

RD-P178 682

FLIGHT TEST EVALUATION OF THE OH-58C MAIN ROTOR BLADE  
EROSION TAPE(U) ARMY AVIATION ENGINEERING FLIGHT  
ACTIVITY EDWARDS AFB CA J R MARTIN ET AL. FEB 96

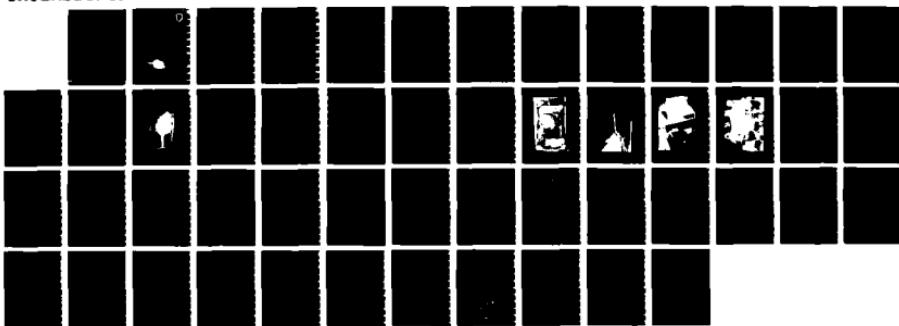
1/1

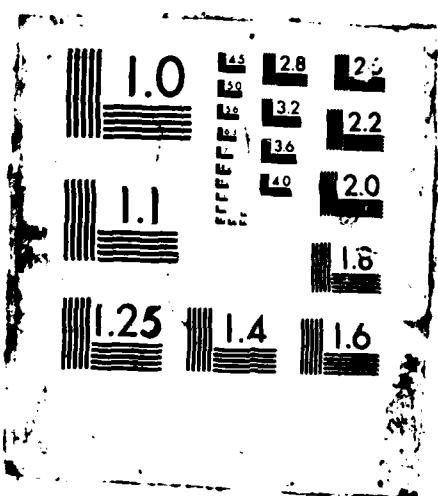
UNCLASSIFIED

USAREFA-94-34

F/G 1/3

ML





USAAEFA PROJECT NO. 84-34



2

## FLIGHT TEST EVALUATION OF THE OH - 58C MAIN ROTOR BLADE EROSION TAPE

JOHN R. MARTIN  
MAJ, AV  
PROJECT OFFICER/PILOT

FREDERICK W. STELLAR  
MAJ, AV  
PROJECT PILOT

RALPH WORATSCHKE  
PROJECT ENGINEER

MATTHEW GRAHAM  
PROJECT ENGINEER

FEBRUARY 1986

FINAL REPORT



DTIC  
ELECTED  
MAR 27 1987  
S E D

Approved for public release, distribution unlimited.

UNITED STATES ARMY AVIATION ENGINEERING FLIGHT ACTIVITY  
EDWARDS AIR FORCE BASE, CALIFORNIA 93523

**DISCLAIMER NOTICE**

**The findings of this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.**

**DISPOSITION INSTRUCTIONS**

**Destroy this report when it is no longer needed. Do not return it to the originator.**

**TRADE NAMES**

**The use of trade names in this report does not constitute an official endorsement or approval of the use of the commercial hardware and software.**

## UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER USAAEFA PROJECT NO. 84-34	2. GOVT ACCESSION NO. AD-A178 602	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) FLIGHT TEST EVALUATION OF THE OH-58C MAIN ROTOR BLADE EROSION TAPE	5. TYPE OF REPORT & PERIOD COVERED FINAL 9 & 23 OCTOBER 1985	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) JOHN R. MARTIN, FREDERICK W. STELLAR RALPH WORATSCHEK, MATTHEW GRAHAM	8. CONTRACT OR GRANT NUMBER(s)	
9. PERFORMING ORGANIZATION NAME AND ADDRESS US ARMY AVN ENGINEERING FLIGHT ACTIVITY EDWARDS AIR FORCE BASE, CA 93523-5000	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS EJ85Y0259EJ W58H02-5086A302	
11. CONTROLLING OFFICE NAME AND ADDRESS US ARMY AVIATION SYSTEMS COMMAND 4300 GOODFELLOW BOULEVARD ST. LOUIS, MO 63120-1798	12. REPORT DATE FEBRUARY 1986	13. NUMBER OF PAGES 54
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) UNCLASSIFIED	
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES Flight test evaluation.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) JOH-58C OH-58C Main Rotor Blades Polyurethane and Stainless Steel Erosion Tapes		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The US Army Aviation Engineering Flight Activity conducted a flight test evaluation of OH-58C main rotor blade erosion tapes between 9 and 23 October 1985. Polyurethane and stainless steel erosion tapes were tested. Hover and level flight performance tests and qualitative handling qualities tests were conducted to determine the effects of applying these leading edge erosion tapes to the main rotor blades of the test JOH-58C. Hover and level flight performance were slightly improved by the installation of the stainless steel tape and		

*cont*  
UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

slightly degraded by the installation of the polyurethane tape. No significant changes in handling qualities were noted as a result of the erosion tape installations. One shortcoming related to the difficult installation of the erosion tapes was noted.

A.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

## TABLE OF CONTENTS

	<u>Page</u>
<b>INTRODUCTION</b>	
Background.....	1
Test Objective.....	1
Description.....	1
Test Scope.....	2
Test Methodology.....	2
 <b>RESULTS AND DISCUSSION</b>	
General.....	4
Performance.....	4
Hover Performance.....	4
Level Flight Performance.....	4
Handling Qualities.....	5
Reliability and Maintainability.....	5
 <b>CONCLUSIONS</b>	
General.....	7
Shortcoming.....	7
 <b>RECOMMENDATION</b> .....	 8
 <b>APPENDIXES</b>	
A. References.....	9
B. Description.....	10
C. Instrumentation.....	15
D. Test Techniques and Data Analysis Methods.....	23
E. Test Data.....	27

### DISTRIBUTION

Accession Per	
NTIS GEN	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unnumbered	<input type="checkbox"/>
Justification	
By _____	
Distribution	
Additional Copy Notes	
Date _____	
Distr. by _____	

A-1



## INTRODUCTION

### BACKGROUND

1. The US Army considers it advantageous to use tape on main rotor blade leading edges to protect the blade from erosion in high wear environments. Two types of tape have been considered for this use: stainless steel and polyurethane. The OH-58C currently has no erosion strip on the main rotor blade leading edge. The US Army Aviation Systems Command (AVSCOM) tasked the US Army Aviation Engineering Flight Activity (USAAEFA) to conduct a flight test evaluation of erosion tape for the OH-58C main rotor blade (ref 1, app A). The USAAEFA forwarded a test plan to AVSCOM (ref 2), which was subsequently approved (ref 3).

### TEST OBJECTIVE

2. The objective of this evaluation was to conduct quantitative performance tests and qualitative handling qualities tests to determine the effect of two different main rotor blade leading edge erosion tapes on the OH-58C helicopter.

### DESCRIPTION

3. The test aircraft, JOH-58C US Army S/N 70-15349, was a modified OH-58C, configured for the Light Combat Helicopter (LCH) mission. The OH-58C is built by Bell Helicopter Textron, Inc. (BHTI). The OH-58C has a single two-bladed, semi-rigid, teetering-type main rotor and a single two-bladed, delta-hinged, semi-rigid teetering-type tail rotor. Maximum gross weight is 3200 pounds. The aircraft is powered by an Allison T63-A-720 engine with an uninstalled intermediate power rating (30 minutes) of 420 shaft horsepower (shp) at standard sea level conditions, which was derated to 317 shp by the main transmission. A detailed description of the OH-58C is contained in the operator's manual (ref 4, app A). Major modifications to the OH-58C for the LCH mission included:

- a. SFENA Stability Augmentation System
- b. Fuel range extenders (590 lb total)
- c. Two-position landing gear
- d. Folding vertical tail fin

e. BHTI 206L-3 tail rotor and drive system (improved tail rotor)

f. Hydraulic boost for the tail rotor

A detailed description of the JOH-58C is included in appendix B and reference 5, appendix A. The erosion tape was either stainless steel (Hughes Helicopter Part No. 87-369D21104) or polyurethane (NSN 9330-00-169-6407) on the leading edge of the outboard 4 ft of both main rotor blades. A detailed description of the erosion tape and tape installation procedure is contained in the test request (ref 1) and appendix B.

#### TEST SCOPE

4. A limited performance and handling qualities evaluation was conducted at Bakersfield (elevation 488 ft), and Edwards AFB (elevation 2302 ft), California. Tests were conducted between 9 and 23 October 1985, consisting of 14 productive test hours in 22 flights. Testing was accomplished within the constraints of the operator's manual (ref 4, app A) and the airworthiness releases for the erosion tapes (ref 6) and the JOH-58C (ref 7). Handling qualities were evaluated using MIL-H-8501A (ref 8) as a guide. Test conditions are presented in table 1.

#### TEST METHODOLOGY

6. Flight test data were recorded on magnetic tape by an on-board instrumentation package (app C). Established flight test techniques were used (refs 9 and 10, app A). Test methods and data analysis are briefly discussed in appendix D. Pilot comments were recorded on cockpit data cards and a cockpit voice recorder.

Table 1. Test Conditions

Type of Test	Erosion Tape Configuration	Cross Weight (lb)	Longitudinal Center of Gravity (FS)	Density Altitude (ft)	Trim True Airspeed (kts)	Referred Rotor Speed (rpm)	Thrust Coefficient ( $\times 10^4$ )
Hover Performance <sup>1</sup>	No Tape	2760 to 3050	110.0 to 111.7	-70	Zero	359 to 357	28.9 to 33.4
	Polyurethane Tape	2740 to 3160	110.3 to 112.4	-300	Zero	350 to 358	28.7 to 34.0
	Stainless Steel Tape	2750 to 3180	110.1 to 112.9	-500	Zero	351 to 359	28.4 to 34.3
Level Flight Performance	No Tape	2910 to 3110	109.2 to 110.6	3810 to 11,240	34 to 104	353.1 to 353.7	34.20, 42.49, 46.86
	Polyurethane Tape	2880 to 3130	109.3 to 110.5	4400 to 11,170	33 to 103	353.0 to 353.8	34.15, 42.51, 46.79
	Stainless Steel Tape	2900 to 3130	109.3 to 110.7	4310 to 11,710	32 to 105	353.3 to 353.9	34.08, 42.38, 46.76
Handling Qualities <sup>2</sup>	No Tape	2940 to 3190	110.0 to 111.6	-300 to 1500	0 to 100	N/A	N/A
	Polyurethane Tape	2900 to 3200	109.8 to 111.7	-300 to 1500	0 to 100	N/A	N/A
	Stainless Steel Tape	3100 to 3200	109.6 to 110.0	2800 to 4500	0 to 100	N/A	N/A

## NOTES:

<sup>1</sup>Free flight hover at 50 ft above ground level.<sup>2</sup>Mission tasks: takeoff, landing, turns, climbs, engine failures and maneuvering flight.

## RESULTS AND DISCUSSION

### GENERAL

7. Hover and level flight performance testing was conducted to determine the effects of applying leading edge erosion tapes to the main rotor blades of the test JOH-58C. Hover and level flight performance were slightly improved by the installation of the stainless steel erosion tape and slightly degraded by the installation of the polyurethane erosion tape. No significant changes in the handling qualities of the JOH-58C were noted as a result of the erosion tape installations. One shortcoming identified was the difficult installation of the erosion tapes.

### PERFORMANCE

#### Hover Performance

8. Out-of-ground effect (OGE) hover performance capability of the JOH-58C was evaluated by determining engine power required to hover at a 50 foot skid height. Testing was accomplished using the free flight hover method. Tests were conducted initially with no tape on the blades to determine a baseline. Testing was then conducted with only polyurethane tape and repeated with only stainless steel tape applied to the leading edge of the main rotor blades. Nondimensional hover performance for blades without tape is shown in figure 1, appendix E; for blades with polyurethane tape in figure 2; and for blades with stainless steel tape in figure 3.

9. The OGE hover performance of the JOH-58C without tape on the main rotor blades was essentially the same as the standard OH-58C as reported in reference 11, appendix A. Hover performance of the JOH-58C was slightly improved by installation of the stainless steel erosion tape and slightly degraded by installation of the polyurethane erosion tape. Power required for OGE hover at maximum gross weight (3200 lb) on a sea-level standard day increased approximately 4.0 shp with the polyurethane tape applied to the main rotor blades and decreased approximately 1.0 shp with the stainless steel tape applied.

#### Level Flight Performance

10. Level flight performance testing was conducted without tape on the main rotor blades, with only polyurethane erosion tape applied to the blades, and with only stainless steel erosion tape applied to the blades. Tests were conducted to determine changes in power required as a function of airspeed, gross weight, and density altitude. The constant referred gross weight and

rotor speed method was used. Data were obtained in zero sideslip stabilized level flight at incremental airspeeds ranging from 33 to 105 knots true airspeed. Results of these tests are presented nondimensionally in figures 4 and 5 and dimensionally in figures 6 through 17, appendix E.

11. The level flight performance of the JOH-58C was slightly improved by the installation of stainless steel erosion tape and slightly degraded by the installation of the polyurethane erosion tape. Power required for all conditions tested increased approximately 1.5 shp with the polyurethane tape applied to the main rotor blades and decreased approximately 3.0 shp with the stainless steel tape applied.

#### HANDLING QUALITIES

12. Handling qualities of the JOH-58C with each erosion tape installed were evaluated qualitatively in conjunction with the performance tests. Areas investigated were hover, takeoff, climb, level turns, descents, gust response, simulated sudden engine failures, stabilized autorotation and maneuvering flight. The handling qualities of the JOH-58C with either erosion tape installed were essentially unchanged from the standard JOH-58C.

#### RELIABILITY AND MAINTAINABILITY

13. Throughout testing, the reliability and maintainability characteristics of the erosion tape installation were observed and evaluated. No specific tests were conducted to verify long-term reliability and/or maintainability characteristics of the erosion tapes due to the short duration (calendar and flight hour) of the program. Installation of the erosion tapes was accomplished without removing the blades from the aircraft. Application instructions for the polyurethane tape stated the tape could be lifted to release entrapped air bubbles and then reaffixed to the blade. The polyurethane tape could be lifted, as per the instructions, but could not be reaffixed to the blade. Stainless steel application was difficult due to the large area of tape required. Application had to be precisely done with little margin for error. If application was correctly done, there was still a requirement to meticulously smooth the many small air bubbles and rivulets which appeared under the surface. These were time-consuming tasks with both types of tape which, if not done properly the first time, required removal of all tape and a return to the start of the entire process. With both types of tape, there was slight debonding (less than

one inch) of tape ends after one or two flights. Neither tape showed a tendency for further debonding during the remaining flights. Polyurethane tape showed slight pitting after one or two flights. Pitting increased only slightly after several flights. Stainless steel tape showed a progressive erosion after each flight, with up to moderate pitting occurring within one inch of the leading edge. Pitting will probably lead to a slight degradation of performance and will require frequent changes of the erosion tape. Difficulty in applying the tapes will lead to increased maintenance hours and lower availability of aircraft. The difficult and time-consuming installation of either erosion tape is a shortcoming.

## CONCLUSIONS

### GENERAL

14. The following conclusions were reached upon completion of testing:

- a. Hover and level flight performance were slightly improved by the installation of the stainless steel tape and slightly degraded by the installation of the polyurethane tape.
- b. Handling qualities were essentially unchanged with either tape installed.
- c. One shortcoming was identified.

### SHORTCOMING

15. The following shortcoming was identified: difficult and time-consuming installation of either erosion tape (para 13).

## APPENDIX A. REFERENCES

1. Letter, AVSCOM, AMSAV-ED, 3 December 1984, subject: Flight Test Evaluation of OH-58C Main Rotor Blade Erosion Tape. (Test Request)
2. Test Plan, USAAEFA Project No. 84-34, *Flight Test Evaluation of OH-58C Main Rotor Blade Erosion Tape*, February 1985.
3. Letter, AVSCOM, AMSAV-ED, 13 May 1985, subject: Test Plan, Flight Test Evaluation of OH-58C Main Rotor Blade Erosion Tape, USAAEFA Project No. 84-34.
4. Operator's Manual, TM 55-1520-235-10, *Army OH-58C Helicopter*, 7 April 1978, with change 35, 17 February 1984.
5. Final Report, USAAEFA Project No. 85-03, *Airworthiness and Flight Characteristics Evaluation of the JOH-58C (OH-58X Surrogate) Helicopter*, February 1986.
6. Letter, AVSCOM, AMSAV-E, 4 February 1985, subject: Airworthiness Release for Flight Operation of OH-58C Helicopter S/N 70-15349 with the Main Rotor Blade Erosion Tape Installed.
7. Letter, AVSCOM, AMSAV-E, 16 February 1983, with revision 5 dated 17 December 1984, subject: Airworthiness Release for Flight Operation of JOH-58C Helicopter S/N 70-15349 in the Light Combat Helicopter (LCH) Configuration.
8. Military Specification, MIL-H-8501A, *Helicopter Flying and Ground Handling Qualities; General Requirements for*, 7 September 1961, with amendment 1, 3 April 1962.
9. Engineering Design Handbook, Headquarters, US Army Materiel Command, AMCP 706-204, *Helicopter Performance Testing*, August 1974.
10. Naval Test Pilot School Flight Test Manual, Naval Air Test Center, USNTPS-FTM-No. 101, *Helicopter Stability and Control*, June 1968.
11. Final Report, USAAEFA Project No. 76-11-2, *Airworthiness and Flight Characteristics Evaluation OH-58C Interim Scout Helicopter*, April 1979.
12. Aviation Unit and Intermediate Maintenance Manual, OH-58A and OH-58C, TM 55-1520-228-23-1, dated 4 August 1978, with change 39, 1 December 1985.

## APPENDIX B. DESCRIPTION

### GENERAL

1. The test aircraft was a JOH-58C helicopter, US Army S/N 70-15349, a modification of the OH-58C. The OH-58C is built by Bell Helicopter Textron, Inc. (BHTI). The OH-58C has a single two-bladed, semi-rigid, teetering-type main rotor and a single two-bladed, delta-hinged, semi-rigid, teetering-type tail rotor. A detailed description of the OH-58C is contained in the operator's manual (ref 4, app A). The major modification for the JOH-58C configuration was addition of the three-axis stability augmentation system (SAS) by the SAS manufacturer, SFENA Corporation. Other modifications for this test included the BHTI 206L-3 tail rotor with accompanying drive shafting and gearbox and a shortened main rotor blade. External configuration was that described in reference 5, appendix A, with the Direct Vision Optics, Forward Looking Infrared System and High Frequency Antenna removed. A detailed description of the JOH-58C is contained in USAAEFA Project No. 85-03 (ref 5). The test aircraft is shown in photo 1.

### WEIGHT AND BALANCE

2. The helicopter configured with all modifications and instrumentation was weighed with no fuel and with full fuel prior to any testing. The weight and longitudinal center of gravity (cg) are presented below:

<u>Weight (lb) / cg (fs)</u>	
No fuel	2438/116.05
Full fuel	2964/116.52

### CONTROL RIGGING

3. A complete flight control rigging check was performed by SFENA Corporation and witnessed by US Army Aviation Engineering Flight Activity (USAAEFA) quality control personnel prior to USAAEFA Project No. 85-03 and used for this test. All flight control rigging was within tolerance in accordance with reference 12, appendix A. Data for the tail rotor rigging check are presented below:

	<u>Direction</u>	<u>Blade Angle</u>
206L-3 tail rotor	Left	22° 30'
	Right	-7° 30'

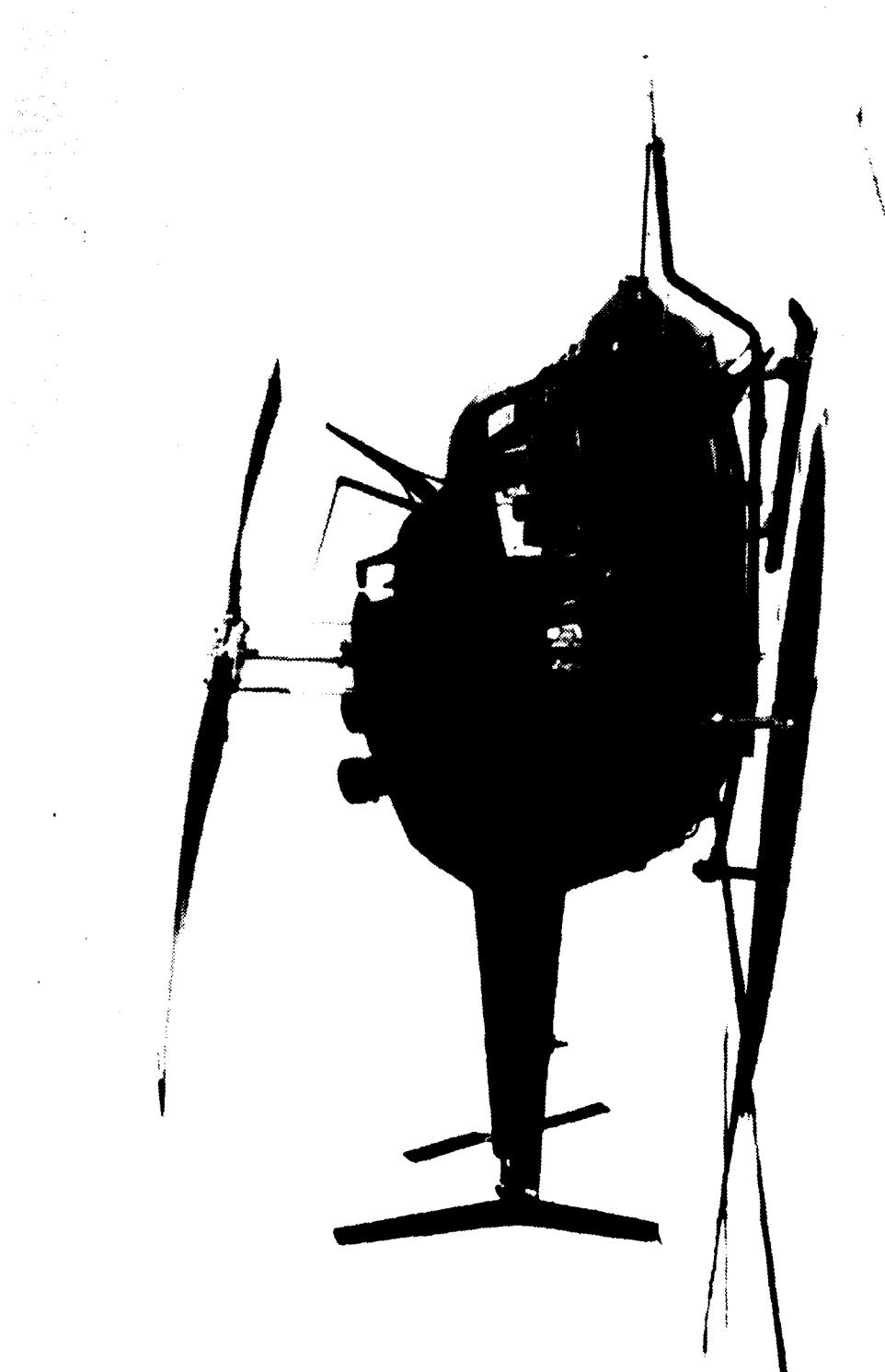


Photo 1. JOH-58C Light Combat Helicopter

## ROTOR SYSTEM

### Tail Rotor

4. The 206L-3 tail rotor (improved tail rotor) incorporates the same airfoil section as the standard OH-58C tail rotor. The diameter is increased by 3 inches. Maximum pitch angle values for the 206L-3 tail rotor are shown in paragraph 3. A hydraulically-boosted tail rotor system was flown for this test.

### Tail Rotor Drive Shaft and Gearbox

5. The tail rotor drive shafting and gearbox were changed to the 206L-3 configuration. The drive shaft is a seven-piece shaft. Each piece in the shaft is identical and has a larger diameter than the one-piece standard drive shaft. The tail rotor gearbox continuous rating is increased from 65 to 85 shaft horsepower.

### Main Rotor

6. In order to maintain main rotor to tail rotor clearance, each main rotor tip cap was shortened by 1.5 inches.

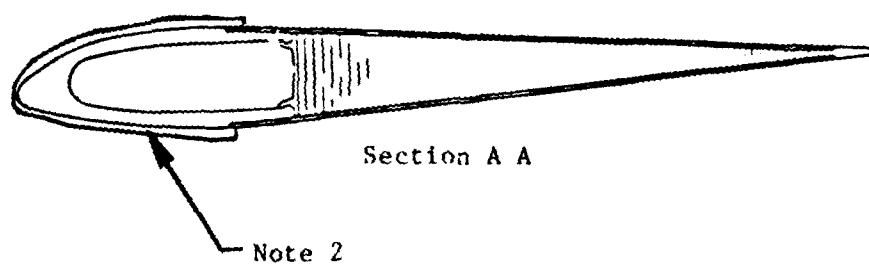
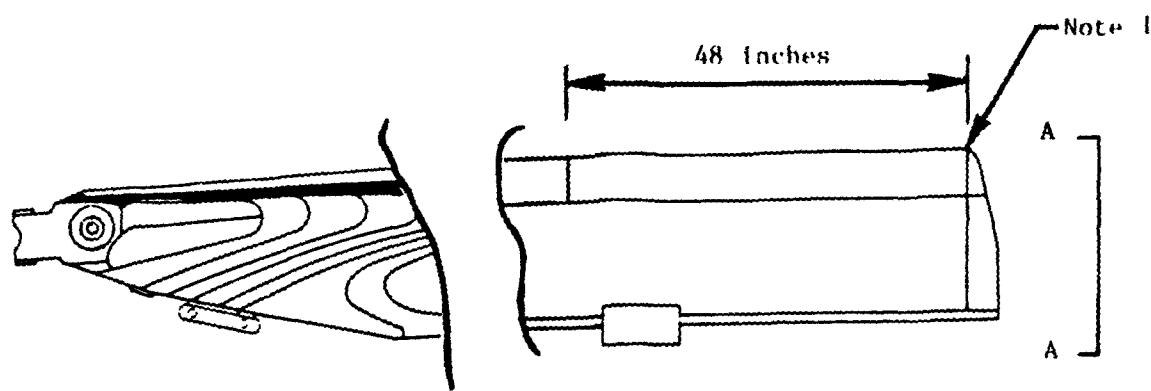
### Stability Augmentation System

7. The OH-58C had a limited authority, three-axis SAS. The SAS used rate gyroscopes to provide rate damping in each axis. Rate integration was used to provide attitude retention. Force trim was provided in the pitch and roll axes. An altitude hold feature was also provided in cruise flight. A detailed SAS description is included in reference 5, appendix A.

## EROSION TAPE

### Polyurethane Tape

8. The polyurethane tape was NSN 9330-00-169-6407 (plastic, strip, pressure sensitive), identified in the OH-58C maintenance manual (Item 120A, table 1-2, ref 12, app A). The tape was 6.0 inches wide by 0.014 inches thick. A strip of tape 48 inches long was applied to the outboard leading edge of each main rotor blade. The tape was applied inboard from the junction of the blade tip cap as shown in figure 1. Prior to application, blades were cleaned with scotchbrite pads and/or naptha. Since the tape was pressure sensitive, it was pressed into place and then smoothed with a roller or spatula. Detailed installation instructions are included in the test request (ref 1).



#### NOTES

1. Tape to extend outboard to the junction of the blade/tip cap.
2. Erosion tape installed with equal widths above and below the leading edge. Tape width is 6.0 inches (polyurethane) or 6.5 inches (stainless steel).

Figure 1. Erosion Tape Installation

Stainless Steel Tape

9. The stainless steel tape was Hughes Helicopter part no. 87-369D21104. The tape was 6.5 inches wide by 0.0027 inches thick. A strip of tape 48 inches long was applied to the leading edge of each main rotor blade. Installation location was the same as for the polyurethane tape (fig. 1). Prior to application, blades were cleaned with 400 grit abrasion paper and solvent. The blade was then heated (not to exceed 120°F) and tape was applied and hand smoothed. Detailed installation instructions are included in the test request (ref 1, app A).

## APPENDIX C. INSTRUMENTATION

1. The test instrumentation system was designed, calibrated, installed, and maintained by the US Army Aviation Engineering Flight Activity. Digital and analog data were obtained from calibrated instrumentation and were recorded on magnetic tape and/or displayed in the cockpit. The instrumentation system consisted of various transducers, signal conditioning units, a ten-bit pulse code modulation encoder, and an Ampex AR 700 tape recorder. Time correlation was accomplished with an onboard-recorded and -displayed Inter-Range Instrumentation Group B format time of day. Various specialized test indicators displayed data to the pilot and engineer continuously during the flight. A boom with a swiveling pitot-static tube, sideslip vane, and angle-of-attack vane was mounted on the nose of the aircraft. Photos 1 through 4 show the instrumentation installation. The boom airspeed system calibration in level flight is shown in figure 1. The engine torquemeter calibration is shown in figure 2.

2. The following parameters were displayed on calibrated instruments in the cockpit:

- Airspeed (boom)
- Airspeed (ship's system)
- Altitude (boom)
- Altitude (ship's system)
- Outside air temperature
- Rotor speed
- Engine torque
- Turbine outlet temperature
- Fuel flow rate
- Fuel used (totalizer)
- Normal acceleration (center of gravity)
- Angle-of-sideslip
- Time of day
- Record counter

3. The following parameters were recorded on magnetic tape:

- Time code
- Run number
- Airspeed (boom)
- Airspeed (ship)
- Altitude (boom)
- Altitude (ship)
- Outside air temperature
- Main rotor speed
- Angle-of-sideslip
- Angle-of-attack
- Engine torque

Turbine outlet temperature  
Gas producer speed  
Power turbine output shaft speed  
Fuel flow rate  
Fuel used  
Control positions  
    Longitudinal  
    Lateral  
    Directional  
    Collective  
Aircraft attitudes and rates  
    Pitch  
    Roll  
    Yaw  
SAS actuator positions  
    Left hand cyclic  
    Right hand cyclic  
    Directional  
Aircraft vertical acceleration (center of gravity)

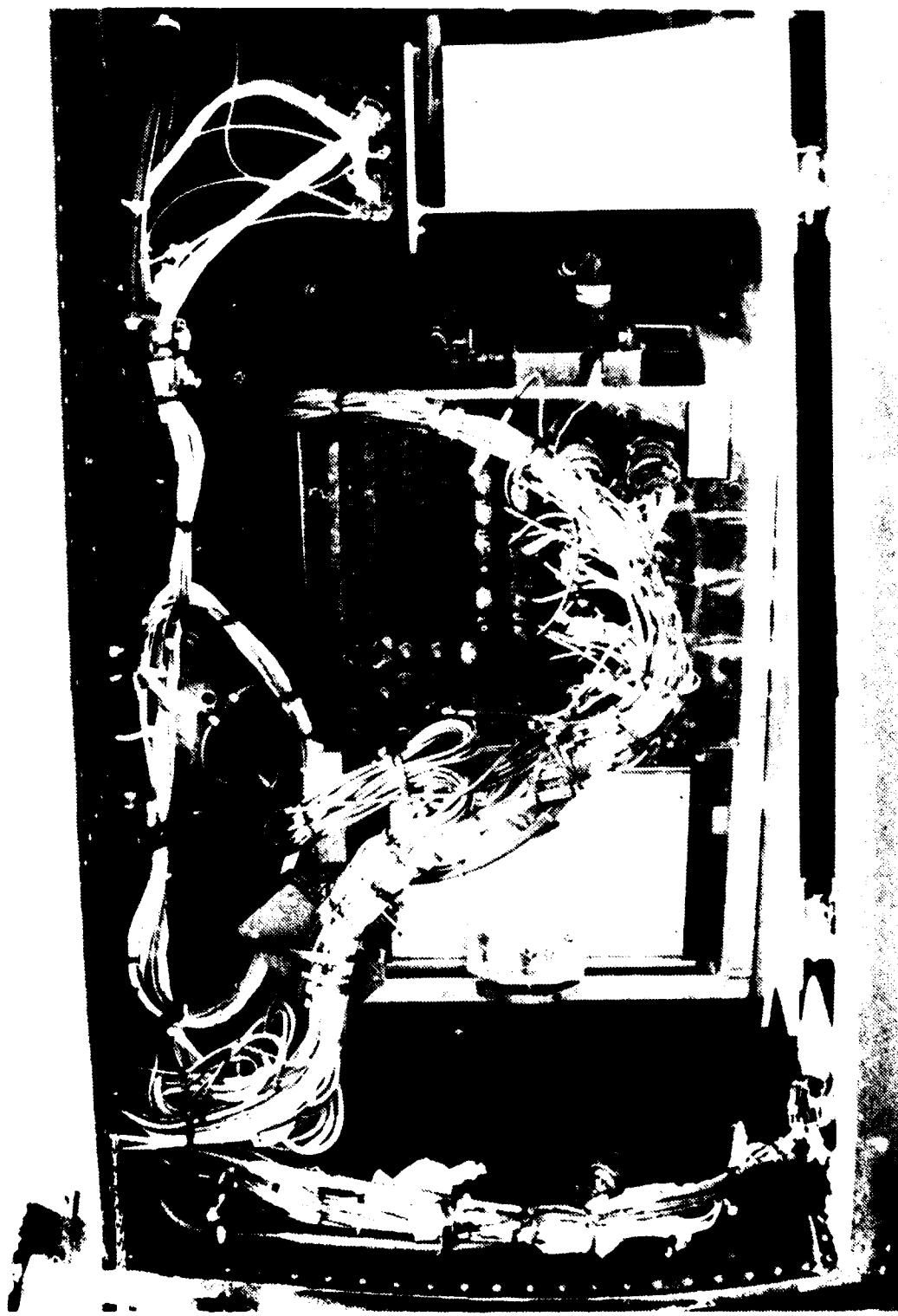


Photo 1. Instrumentation Installation in Avionics Compartment

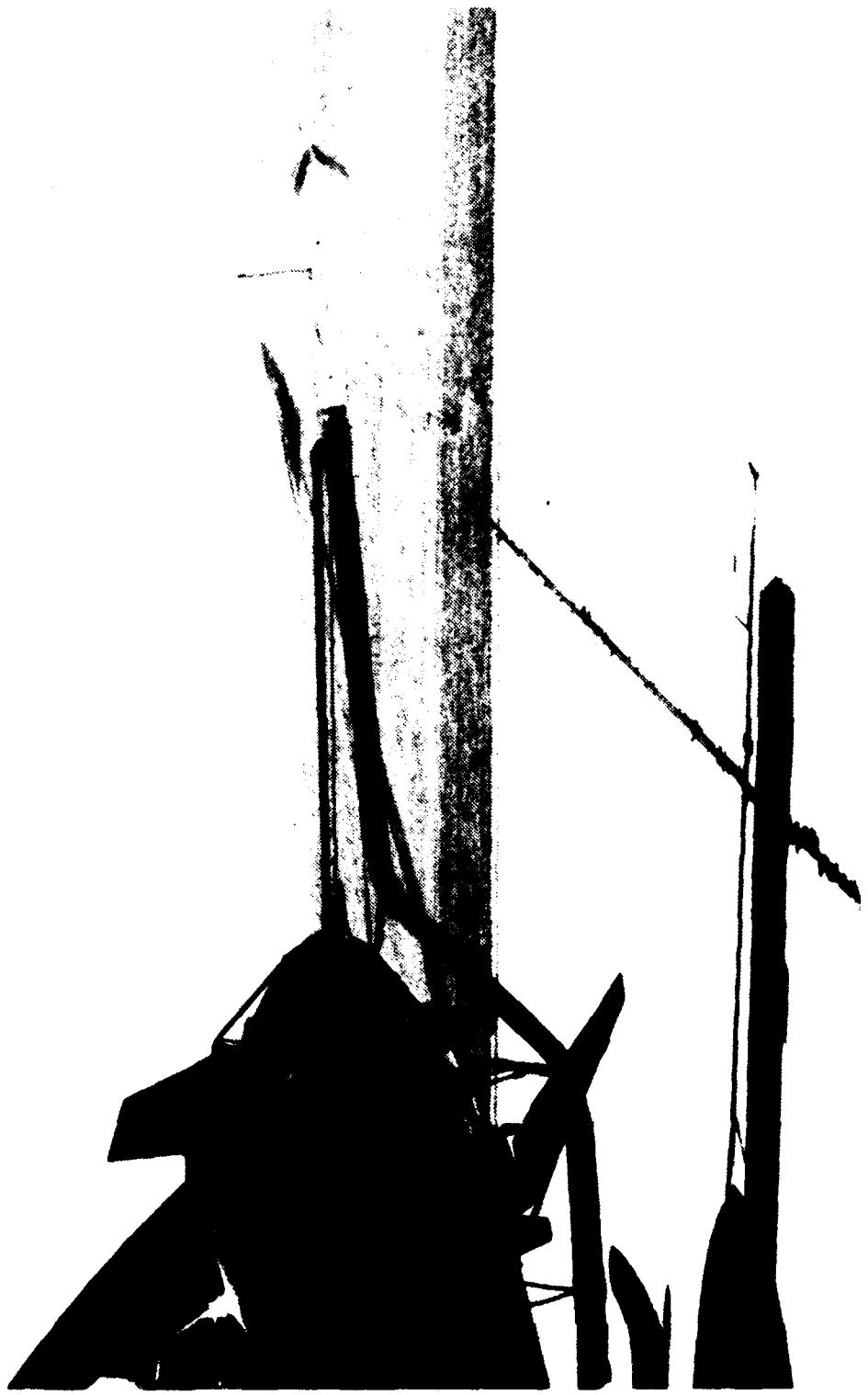


Photo 2. Airspeed Boom (Attached to Underside of Aircraft)



Photo 3. Voice and Pulse Code Modulation Recorders Installed in Passenger Compartment

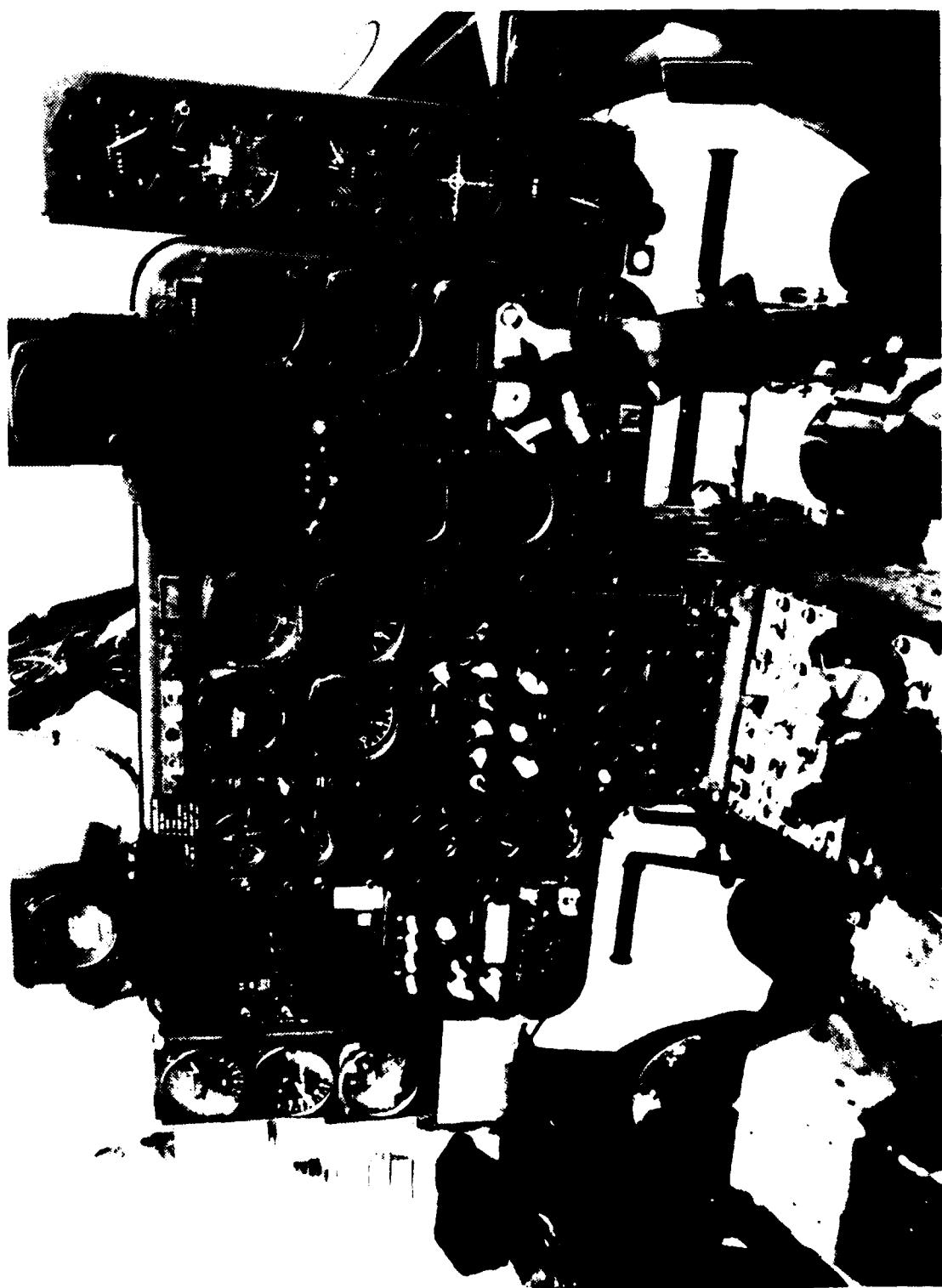


Photo 4. Cockpit Instrumentation

FIGURE 1  
BOOM SYSTEM AIRSPEED CALIBRATION IN LEVEL FLIGHT  
JOH-58C USA S/N 70-15349

Avg Gross Weight (lb)	Avg Longitudinal CG Location (ft)	Avg Density (ft <sup>-3</sup> )	Avg OAT (deg C)	Avg Rotor Speed (RPM)
2990	109.2 (MID)	5480	7.5	353

NOTE: TRAILING BOMB METHOD

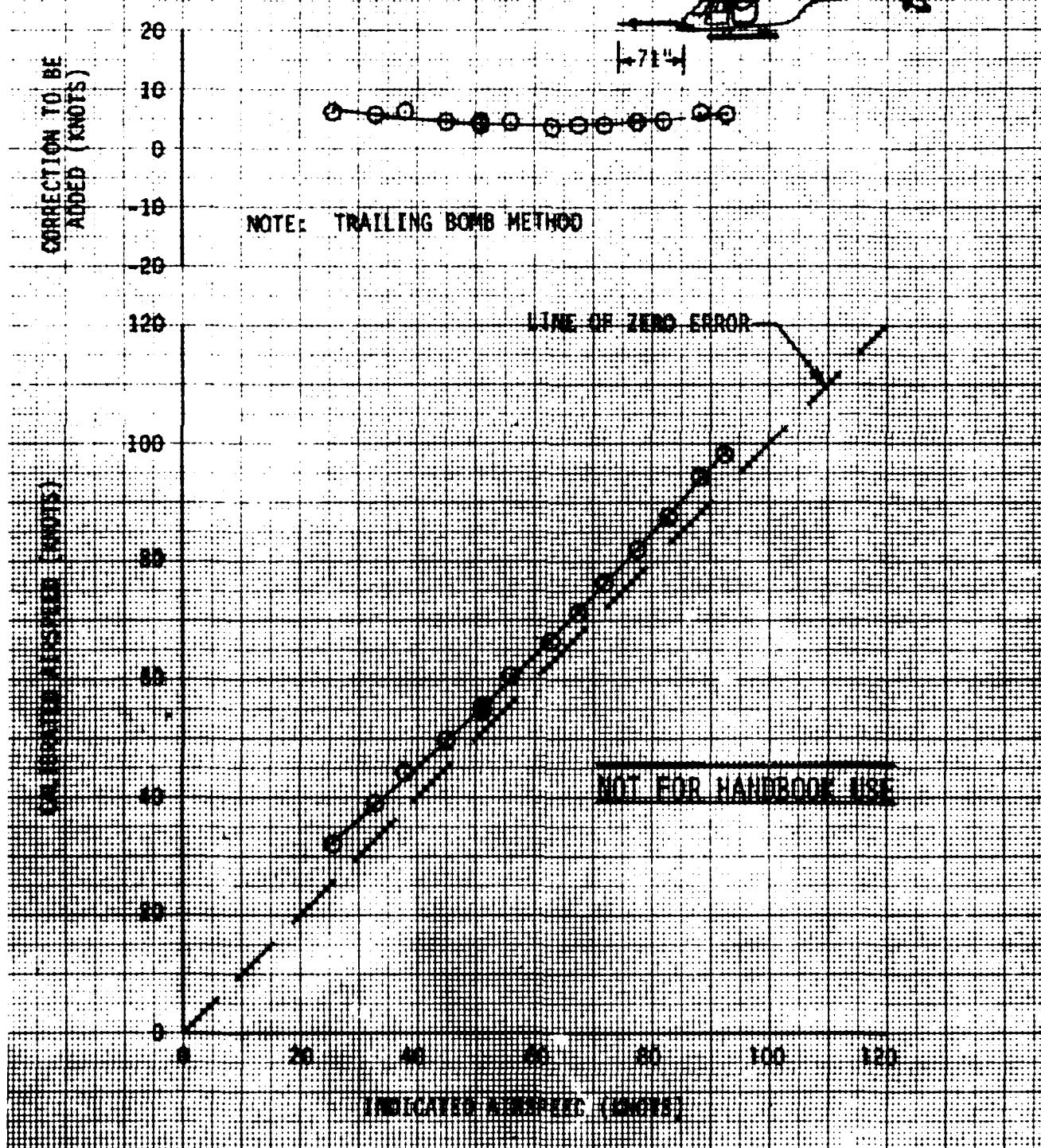
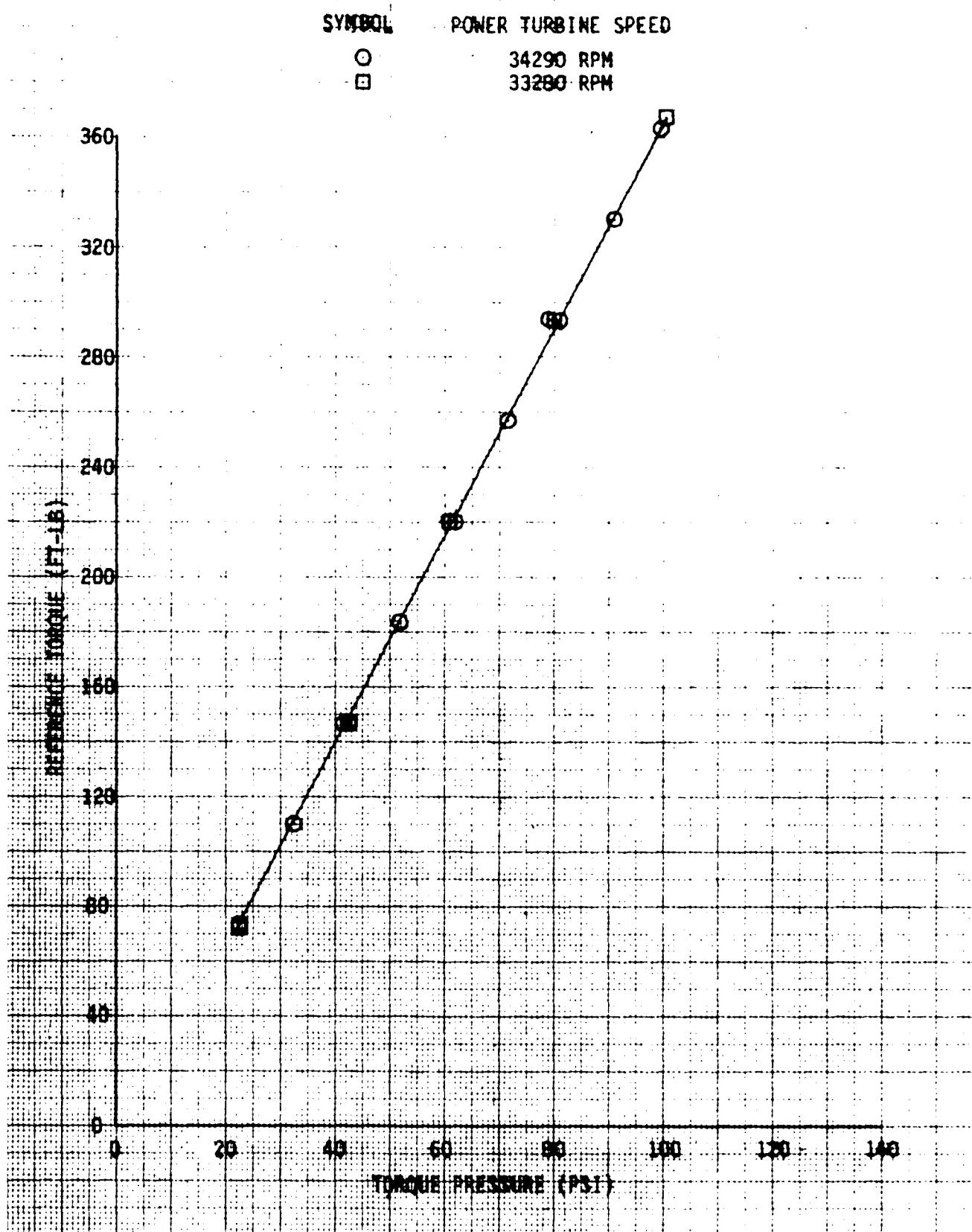


FIGURE 2  
ENGINE TORQUEMETER CALIBRATION  
ALLISON ENGINE MODEL T63-A-720 S/N 404458



## APPENDIX D. TEST TECHNIQUES AND DATA ANALYSIS METHODS

### PERFORMANCE

1. The helicopter performance test data were generalized by use of nondimensional coefficients. Effects of compressibility and blade stall were not separated and defined. The following non-dimensional coefficients were used to generalize the hover and level flight test results obtained during this flight test program.

a. Coefficient of power ( $C_p$ ):

$$C_p = \frac{SHP \text{ (550)}}{\rho A (\Omega R)^3} \quad (1)$$

b. Coefficient of thrust ( $C_T$ ):

$$C_T = \frac{\text{Thrust}}{\rho A (\Omega R)^2} \quad (2)$$

c. Advance ratio ( $\mu$ ):

$$\mu = \frac{1.6878 V_T}{\Omega R} \quad (3)$$

d. Advancing tip Mach number ( $M_{tip}$ ):

$$M_{tip} = \frac{1.6878 V_T + (\Omega R)}{a} \quad (4)$$

Where:

SHP = Engine output shaft horsepower

550 = Conversion factor (ft-lb/sec/shp)

$\rho$  = Air density (slug/ft<sup>3</sup>) =  $\sigma \times 0.002376881$

$\sigma$  = Density ratio =  $\delta/\theta$

$\Lambda$  = Main rotor disc area (ft<sup>2</sup>) = 966.52

$\Omega$  = Main rotor angular velocity (radian/sec) = 37.07 (at 354 rpm)

R = Main rotor radius (ft) = 17.54

Thrust = Gross weight (lb)

1.68/8 Conversion factor (ft/sec/knot)

$V_T$  = True airspeed (knot)

$a$  = Speed of sound (ft/sec) =  $1116.45\sqrt{0}$

$\beta = (T + 273.15)/288.15$

$T$  = Ambient air temperature ( $^{\circ}$ C)

$$\beta = \left( 1 - \frac{H_p}{145442} \right)^{5.25585}$$

$H_p$  = Pressure altitude (ft)

For a rotor speed of 354 rpm, the following constants were used:

$\omega R = 650.21$  ft/sec

$A(\omega R)^2 = 408618602.6$  ft<sup>4</sup>/sec<sup>2</sup>

$A(\omega R)^3 = 2.6568790 \times 10^{11}$  ft<sup>5</sup>/sec<sup>3</sup>

#### Shaft Horsepower Required

2. The engine output shaft torque was determined from the engine manufacturer's torque system. The relationship of measured torque pressure to engine output shaft torque (ft-lb) as determined in the engine test cell calibration is shown in figure 2, appendix C. This output shp was determined from the engine output shaft torque and rotational speed by the following equation:

$$SHP = \frac{2\pi \times N_p \times Q}{33,000} \quad (5)$$

Where:

$N_p$  = Engine output shaft rotational speed (rpm)

$Q$  = Engine output shaft torque (ft-lb)

33,000 = Conversion factor (ft-lb/min/shp)

#### HOVER PERFORMANCE

3. Hover performance data were obtained at 50-foot skid height by the free flight hover technique. All hover tests were conducted in winds of less than 3 knots. Atmospheric pressure, temperature, and wind velocity were recorded from a ground weather station. Free flight hover tests consisted of stabilizing the helicopter at a desired height with reference to a premeasured weighted cord

hung from the aircraft. Ballast was incrementally removed from the aircraft until the minimum gross weight was obtained. All hover data were reduced to nondimensional parameters of  $C_p$  and  $C_T$  (equations 1 and 2, respectively).

#### Level Flight Performance and Specific Range

4. Level flight performance data were reduced using equations 1, 2 and 3. Each speed power was flown at a predetermined constant  $C_T$  by maintaining constant referred gross weight ( $W/\delta$ ) and referred rotor speed ( $N/\sqrt{\theta}$ ). A constant  $W/\delta$  was maintained by increasing pressure altitude (decreasing ambient pressure ratio ( $\delta$ )) as the aircraft gross weight decreased due to fuel burnoff. Rotor speed was also varied to maintain a constant  $N/\sqrt{\theta}$  as the ambient air temperature varied.

5. Test day (measured) level flight power was corrected to standard day conditions (average for the flight) by assuming that the test day dimensionless parameters  $C_p$ ,  $C_T$ , and  $\mu_t$  are identical to  $C_p$ ,  $C_T$ , and  $\mu_s$ , respectively.

From equations 1 and 3, the following relationship can be derived:

$$SHP_s = SHP_t \frac{\rho_s}{\rho_t} \left( \frac{\Omega_s}{\Omega_t} \right)^3 \quad (6)$$

$$V_T = V_T \frac{\Omega_s}{\Omega_t} \quad (7)$$

6. Test specific range was calculated using level flight performance data and the measured fuel flow.

$$SR = \frac{V_T}{W_f} \quad (8)$$

Where:

SR = Specific range (nautical air miles per pound of fuel)  
 $V_T$  = True airspeed (knot)  
 $W_f$  = Fuel flow (lb/hr)

### HANDLING QUALITIES

7. Handling qualities data were qualitatively evaluated using standard test methods as described in reference 9, appendix A. The definition of shortcoming used during this test is as follows: an imperfection or malfunction occurring during the life cycle of equipment which must be reported and which should be corrected to increase efficiency and to render the equipment completely serviceable. It will not cause an immediate breakdown, jeopardize safe operation, or materially reduce the usability of the material or end product.

### AIRSPEED CALIBRATION

8. The boom and ship's pitot-static systems were calibrated by using the trailing bomb method to determine the airspeed position error. Calibrated airspeed ( $V_{cal}$ ) was obtained by correcting indicated airspeed ( $V_i$ ) using instrument ( $\Delta V_{ic}$ ) and position ( $\Delta V_{pc}$ ) error corrections.

$$V_{cal} = V_i + \Delta V_{ic} + \Delta V_{pc} \quad (1)$$

9. True airspeed ( $V_t$ ) was calculated from the calibrated airspeed and density ratio.

$$V_t = \frac{V_{cal}}{\sqrt{\sigma}}$$

### WEIGHT AND BALANCE

10. Prior to testing, the aircraft gross weight and center of gravity (cg) location were determined by using calibrated scales. The aircraft was weighed without fuel and with instrumentation on board. The aircraft weight with no fuel was 2438 pounds, with a longitudinal cg location at fuselage station 116.05.

## APPENDIX E. TEST DATA

### INDEX

#### Figure

Hover Performance  
Level Flight Performance

#### Figure Number

1 through 3  
4 through 17

FIGURE 1  
NONDIMENSIONAL HOVERING PERFORMANCE  
JOH-58C USA S/N 70-15349  
SKID HEIGHT = 50 FEET

SYMBOL	ROTOR SPEED (RPM)	DENSITY ALTITUDE (FT)	OAT (°C)
○	353-354	-70	10.5
□	350	-70	10.5
△	346-347	-70	10.5

34

NOTES: 1. FREE FLIGHT HOVER TECHNIQUE  
2. WINDS LESS THAN 3 KNOTS  
3. VERTICAL HEIGHT FROM BOTTOM OF SKID  
TO CENTER OF ROTOR HUB = 9.3 FEET  
4. NO TAPE ON BLADES

32

30

28

26

24

22

20

18

POWER COEFFICIENT,  $C_p \times 10^5 = \frac{P_{HGT}}{SHP} \times 50 \times 10^5$

26

28

30

32

34

36

38

$$\text{THRUST COEFFICIENT, } C_T \times 10^4 = \frac{G_W}{\rho A(\Omega R)^2} \times 10^4$$

FAIRING DERIVED FROM  
USAAEFA PROJECT  
REPORT NO. 76-11-2

FIGURE 2  
NONDIMENSIONAL HOVERING PERFORMANCE  
JOH-58C USA S/N 70-15349  
SKID HEIGHT = 50 FEET

SYMBOL	ROTOR SPEED (RPM)	DENSITY ALTITUDE (FT)	OAT (°C)
○	353-354	-300	9.0
□	349-350	-300	9.0
△	346-347	-300	9.0

34      NOTES: 1. FREE FLIGHT HOVER TECHNIQUE  
 2. WINDS LESS THAN 3 KNOTS  
 3. VERTICAL HEIGHT FROM BOTTOM OF SKID  
       TO CENTER OF ROTOR HUB = 9.3 FEET  
 4. POLYURETHANE TAPE INSTALLED ON MAIN  
       ROTOR BLADES

32

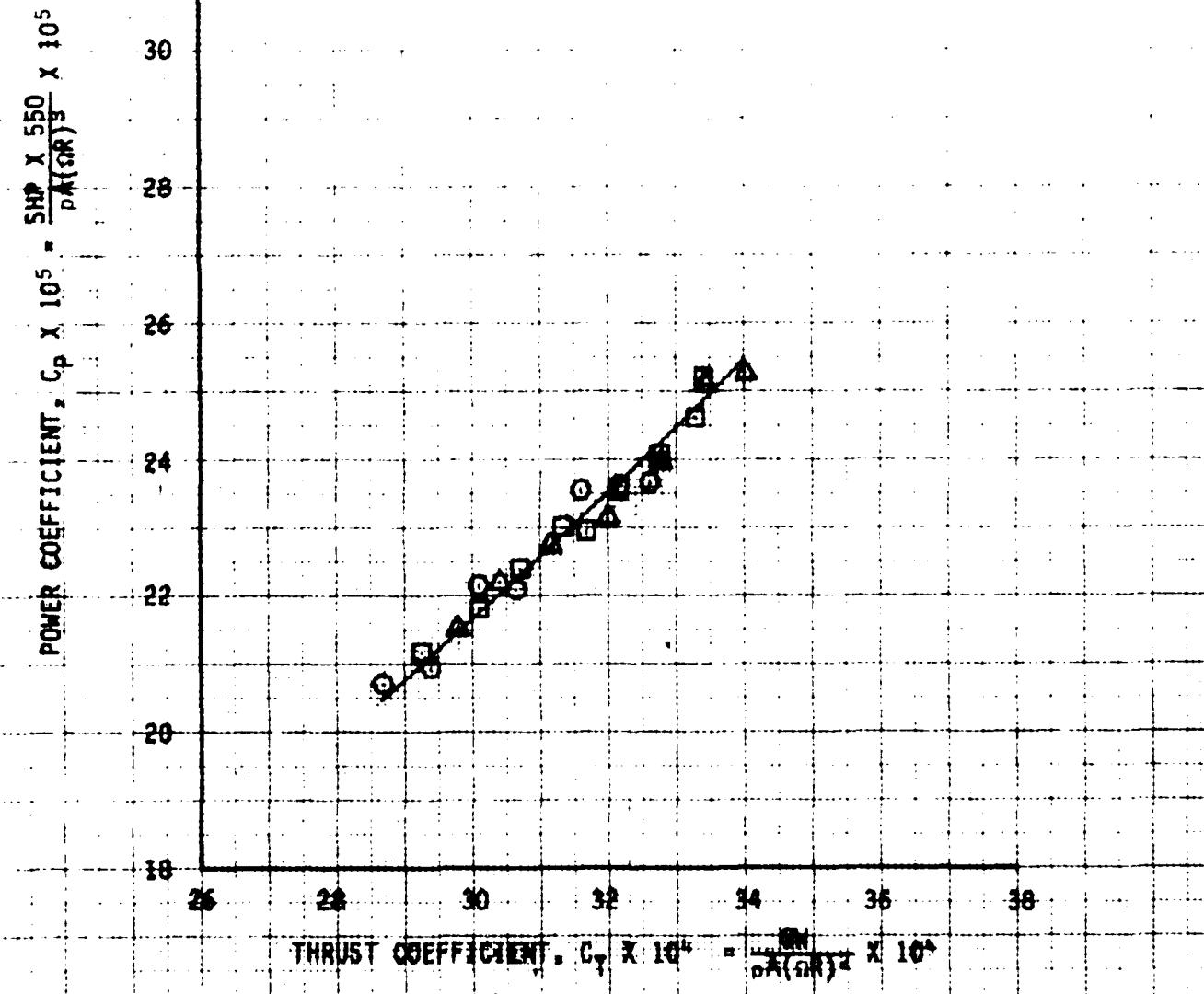


FIGURE 3  
NONDIMENSIONAL HOVERING PERFORMANCE  
JOH-5BC USA S/N 70-15349  
SKID HEIGHT = 50 FEET

SYMBOL	ROTOR SPEED (RPM)	DENSITY ALTITUDE (FT.)	DAT (°C)
○	353-358	-500	7.5
□	349-350	-500	7.5
△	346-347	-500	7.5

34      NOTES: 1. FREE FLIGHT HOVER TECHNIQUE  
         2. WINDS LESS THAN 3 KNOTS  
         3. VERTICAL HEIGHT FROM BOTTOM OF SKID  
            TO CENTER OF ROTOR HUB = 9.3 FEET  
         4. STAINLESS STEEL TAPE INSTALLED ON  
            MAIN ROTOR BLADES

32

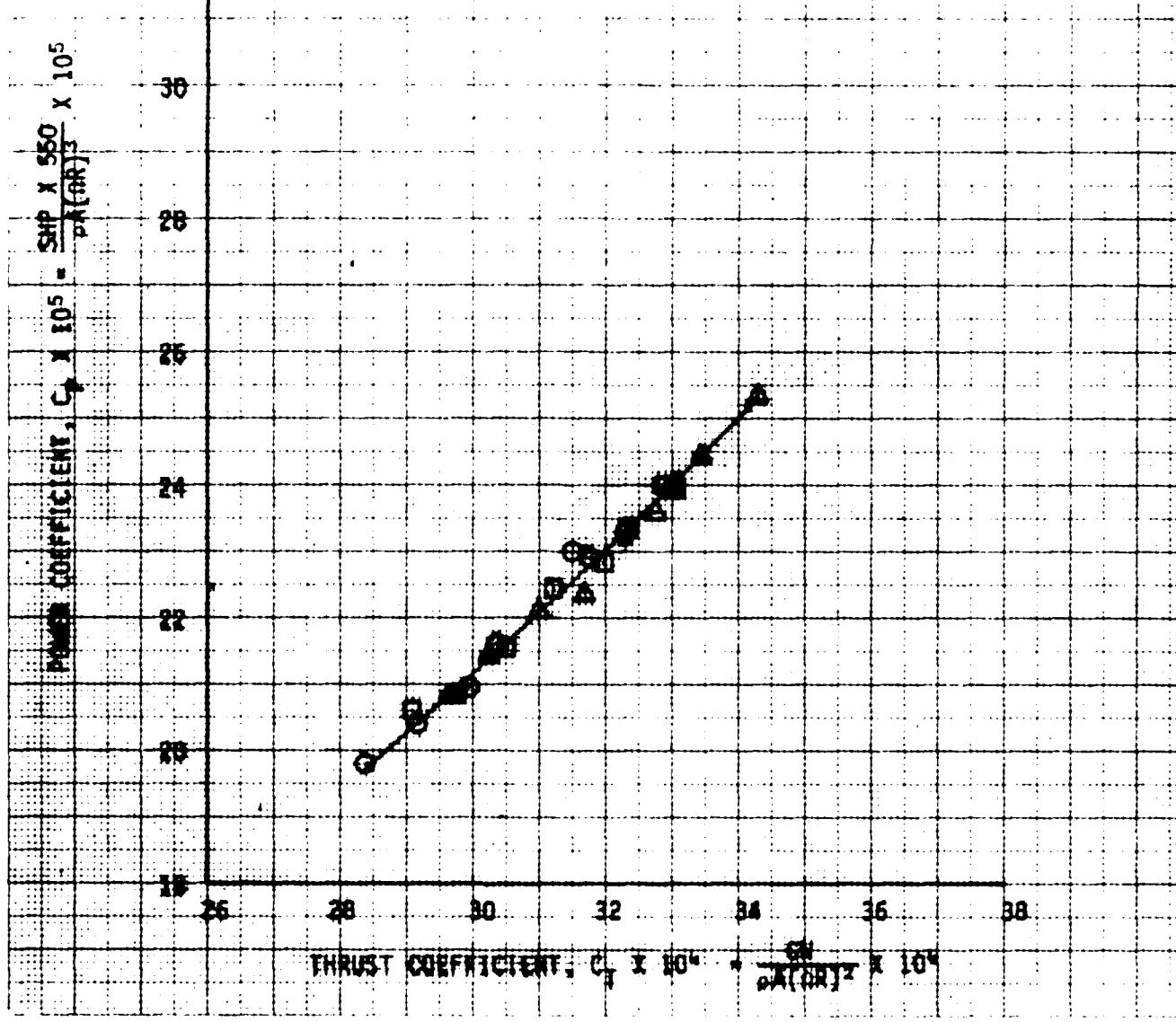


FIGURE 14  
NONDIMENSIONAL FLOWFIELD PERFORMANCE  
MEN-536 USAF STAN 70-19349

NOTES: 1) NO TAPERED BLADES  
2) 74% TIP SLIP  
3) NONDIMENSIONAL FLOW = 7.5 (0.975 FLOW)  
4) AREA FLOW = 353.5

5) CURVES DERIVED FROM FIGURES 6 THROUGH 13

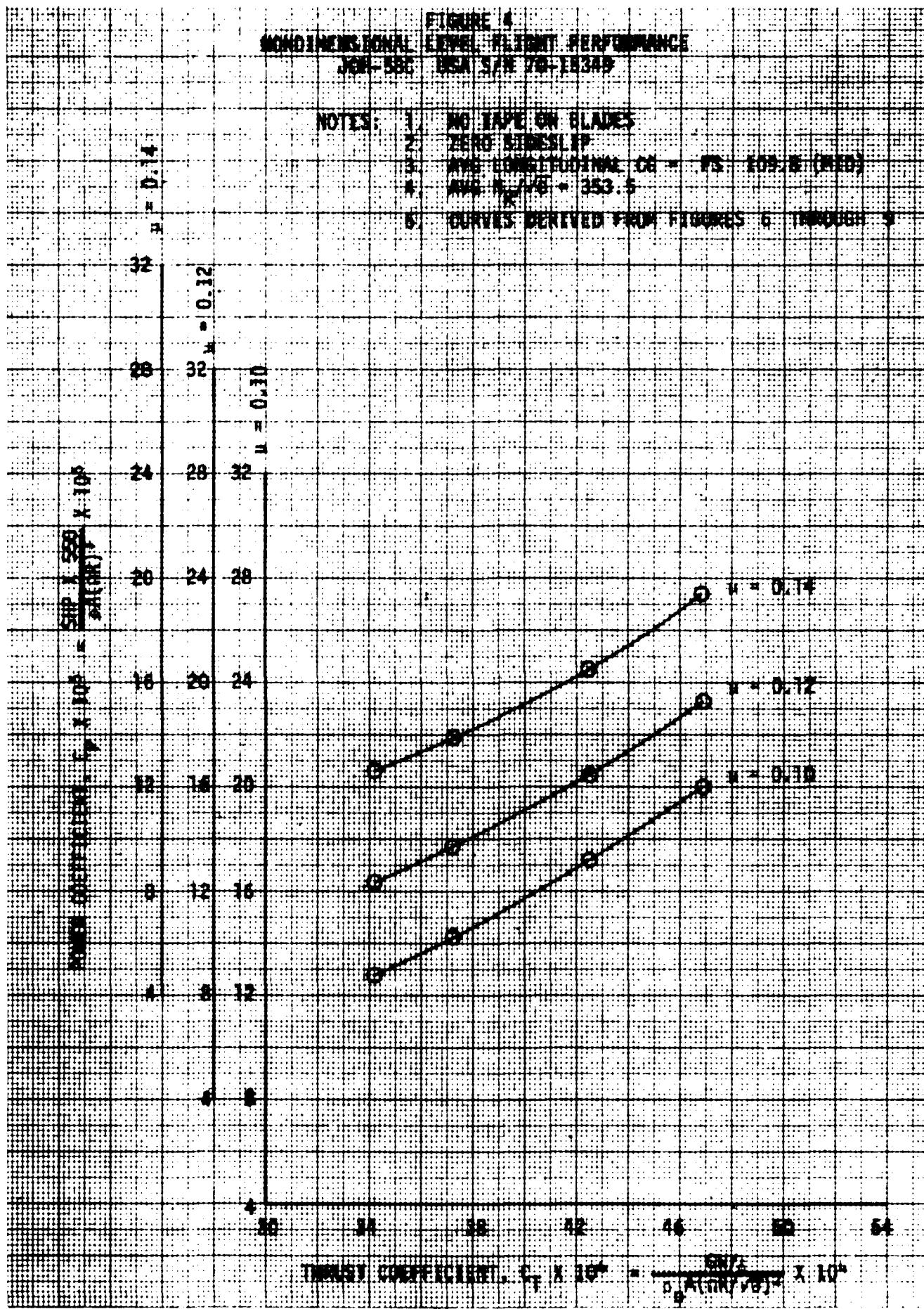


FIGURE 5  
NONDIMENSIONAL LEVEL FLIGHT PERFORMANCE  
JOH-500 USA S/N 70-15349

NOTES: 1. NO TAPE ON BLADES  
2. ZERO SIDESLIP  
3. AVG LATERAL/TELLING CG = FS 109.8 (MID)  
4. AVG  $W_{L/T}$  = 363.5  
5. CURVES DERIVED FROM FIGURES 6 THROUGH 9

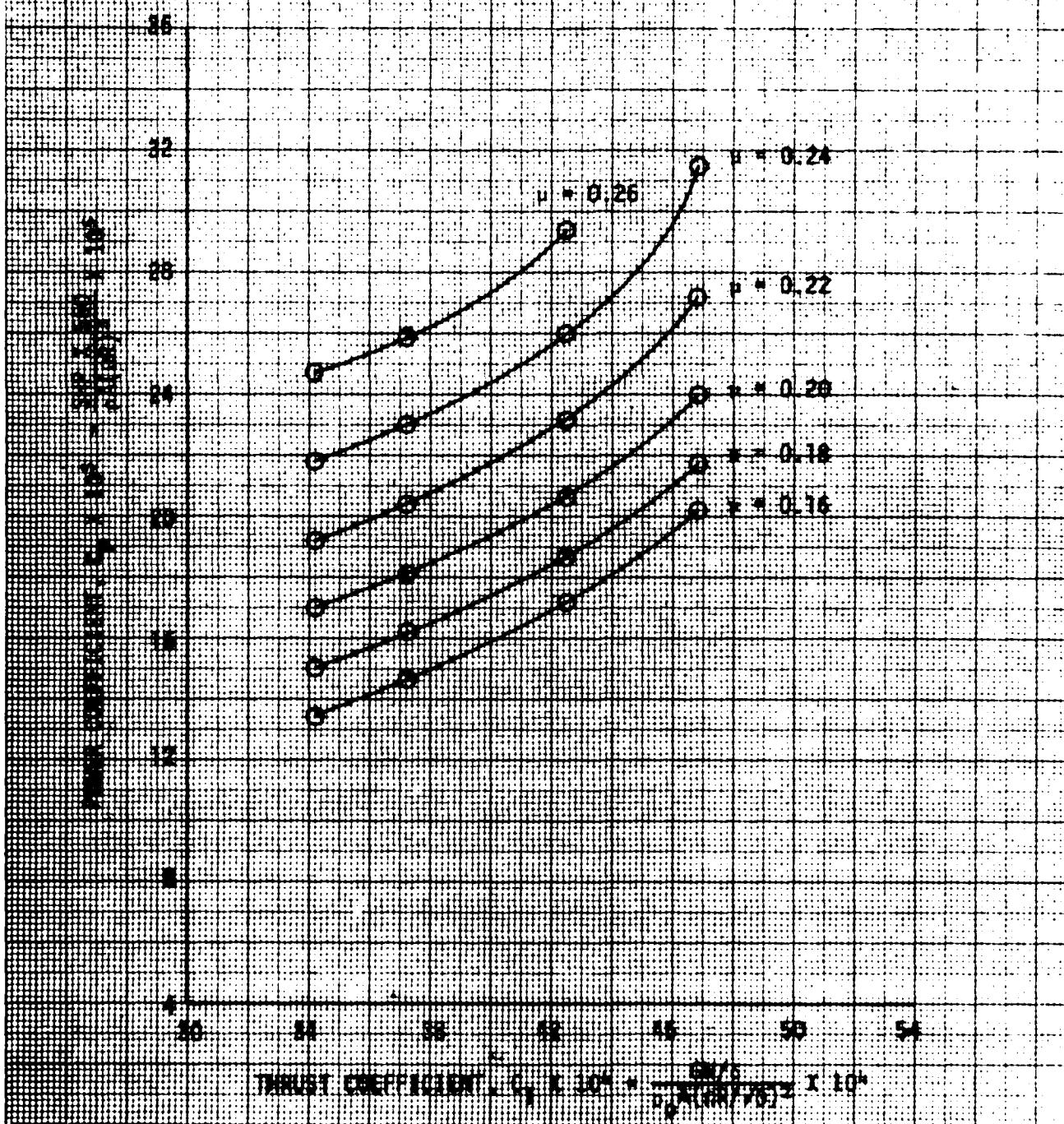


FIGURE 6  
LEVEL FLIGHT PERFORMANCE  
JOH-58C USA S/N 70-15349

Avg Gross Weight (LB)	Avg CG Location Long (FS) Lat (BL)	Avg Density Altitude (FT)	Avg OAT (Deg C)	Avg Referred Rotor Speed (RPM)	Avg C <sub>T</sub>
2910	110.6(AFT) 0.1 MID	3810	11.0	353.1	0.003420

NOTES: 1. ZERO SIDESLIP  
2. NO TAPE ON BLADES

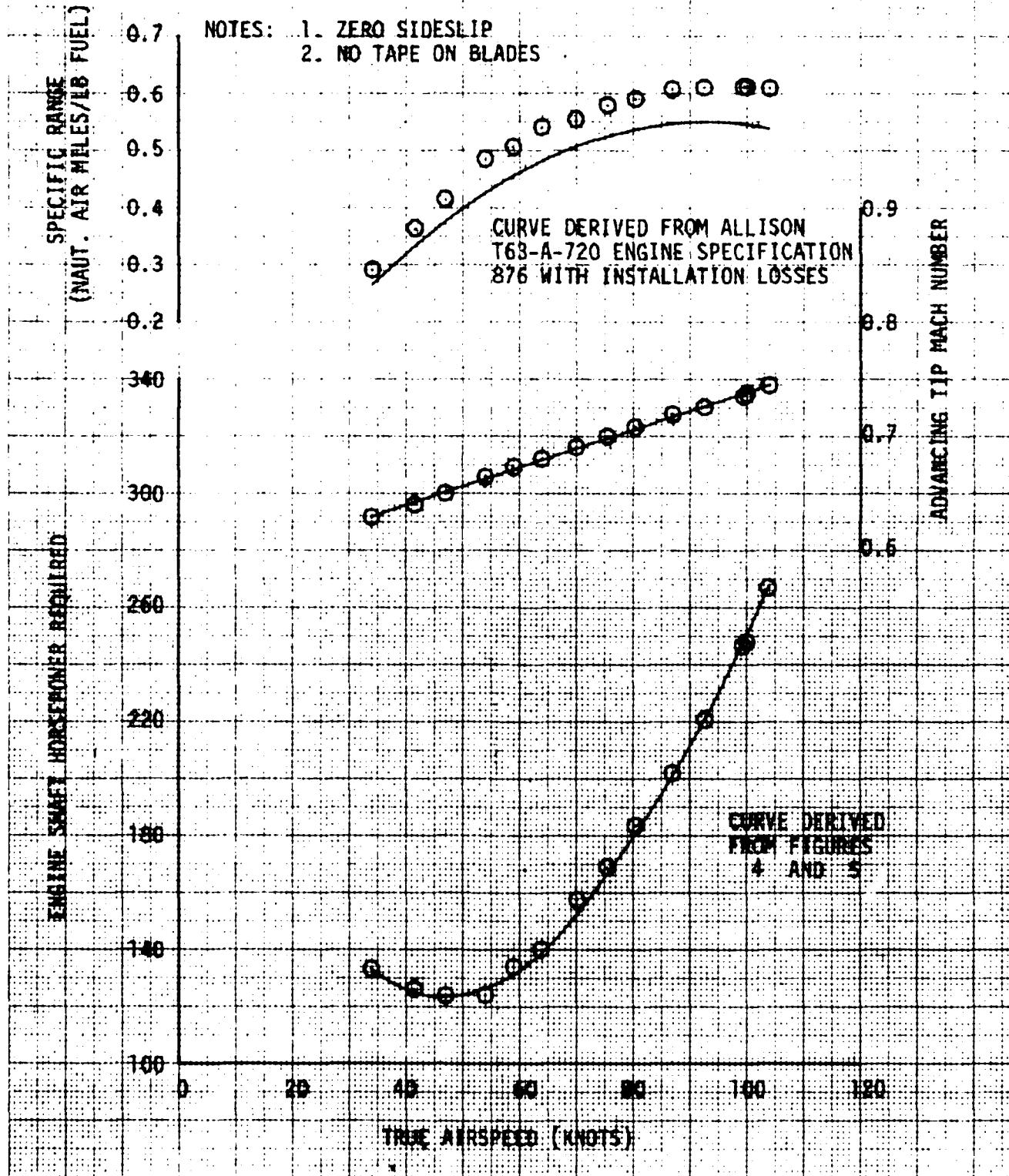


FIGURE 7  
LEVEL FLIGHT PERFORMANCE  
JOH-58C USA S/N 70-15349

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG LAT (BL)	AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG C)	AVG REFERRED ROTOR SPEED (RPM)	AVG CT
2990	109.2(MID)	0.1 MID	5480	7.5	353.9	0.003723

NOTES: 1. ZERO SIDESLIP.  
2. NO TAPE ON BLADES

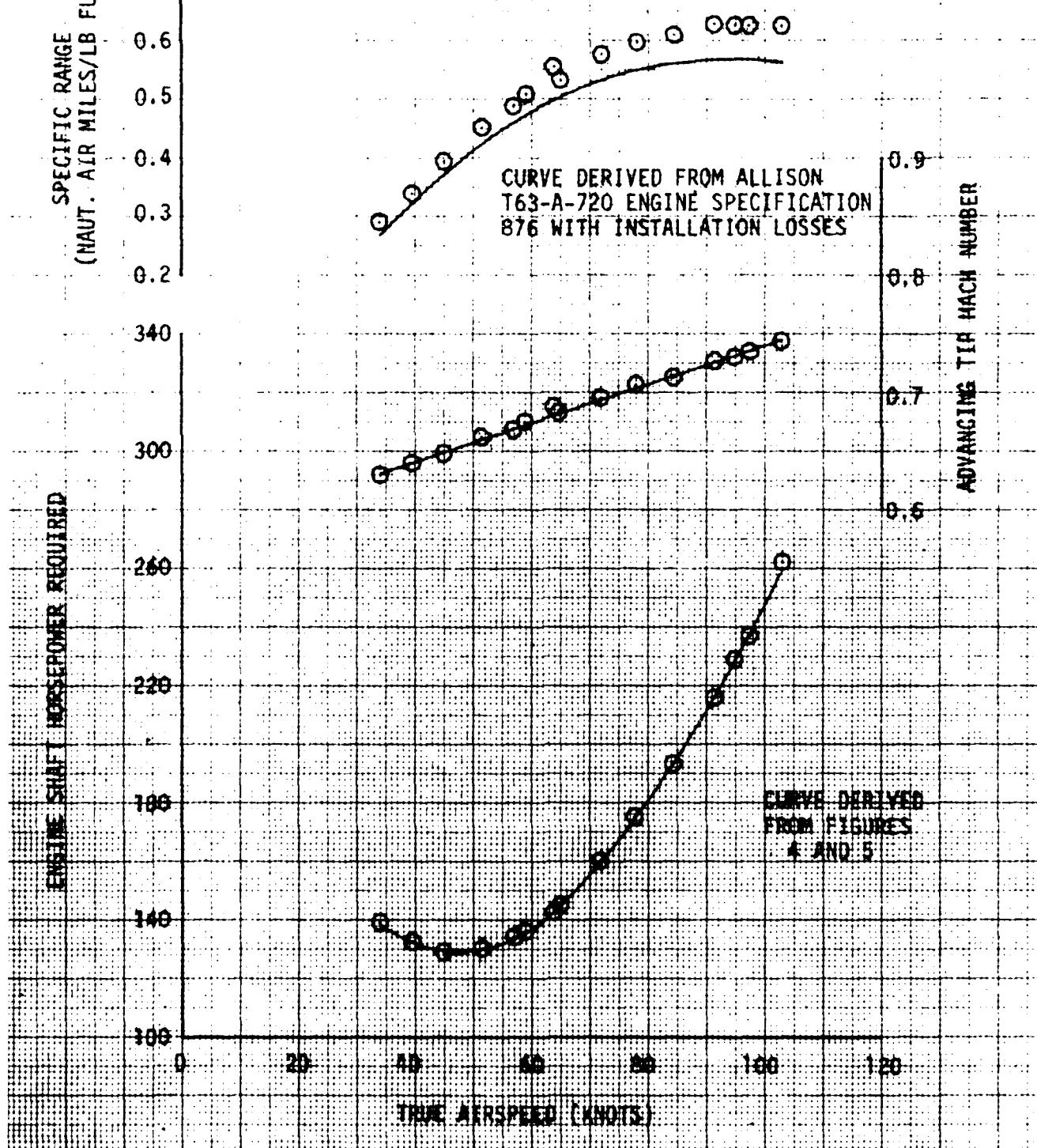


FIGURE 8  
LEVEL FLIGHT PERFORMANCE  
JOH-58C USA S/N 70-15349

AVG GROSS WEIGHT (LB)	AVG CG LOCATION	AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG C)	AVG REFERRED ROTOR SPEED (RPM)	AVG C <sub>T</sub>
3100	109.6(MID) LONG (FS) 0.1 LAT (BL) MID	8380	6.0	353.7	0.004249

NOTES: 1. ZERO SIDESLIP  
2. NO TAPE ON BLADES

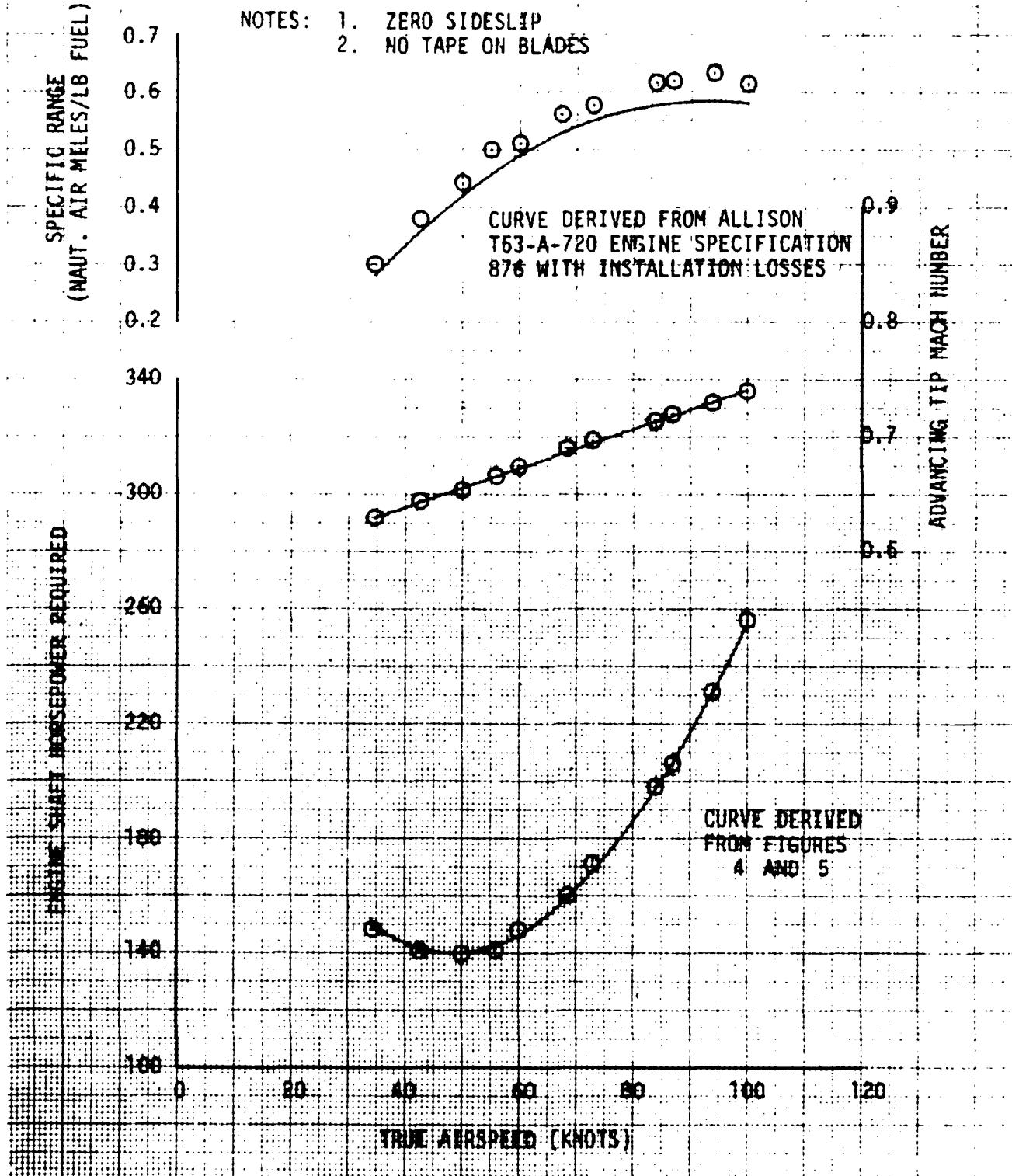


FIGURE 9  
LEVEL FLIGHT PERFORMANCE  
JOH-58C USA S/N 70-15349

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG C)	AVG REFERRED ROTOR SPEED (RPM)	AVG C <sub>T</sub>
3110	109.7(MID)	0.1 MID	11,240	5.5	353.1	0.004686

NOTES: 1. ZERO SIDESLIP  
2. NO TAPE ON BLADES

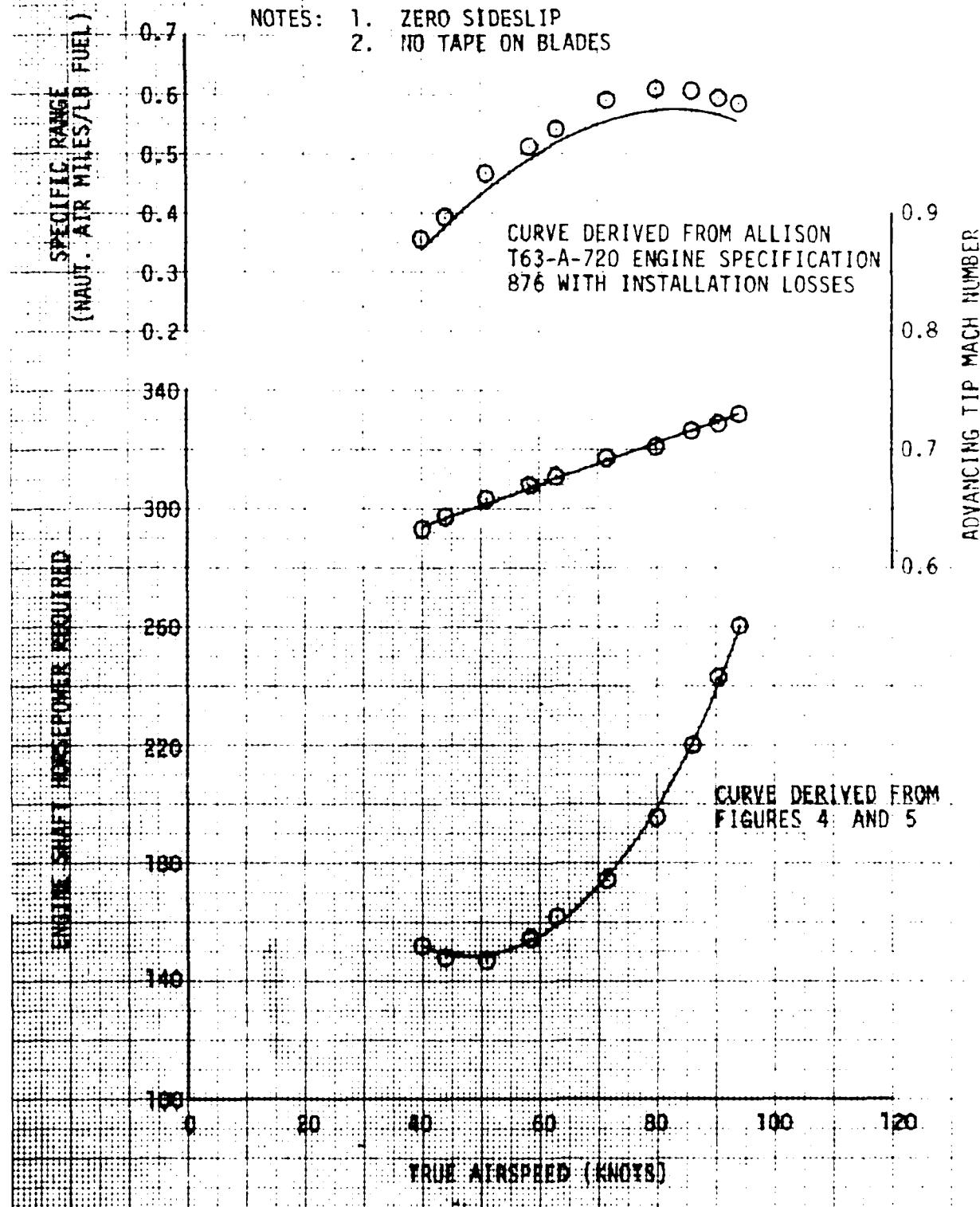


FIGURE 1G  
LEVEL FLIGHT PERFORMANCE  
JCH-58C USA S/N 70-19349

Avg Gross Weight (lb)	Avg CG Location (FS)	Avg Density (lb/ft <sup>3</sup> )	Avg OAT (deg C)	Avg Referred Rotor Speed (RPM)	Avg T (lb)	
2880	110.5 (AFT)	1.0	4400	12.5	363.7	0.003415

NOTES: 1. ZERO SIDESLIP  
2. POLYURETHANE TAPE  
APPLIED TO MAIN  
ROTOR BLADE

CURVE DERIVED FROM ALLISON  
T63-A-720 ENGINE SPECIFICATION  
876 WITH INSTALLATION LOSSES

CURVE DERIVED FROM  
FIGURES 4 AND 5  
PLUS  $\Delta \text{SHP} = +1.5 \text{ SHP}$

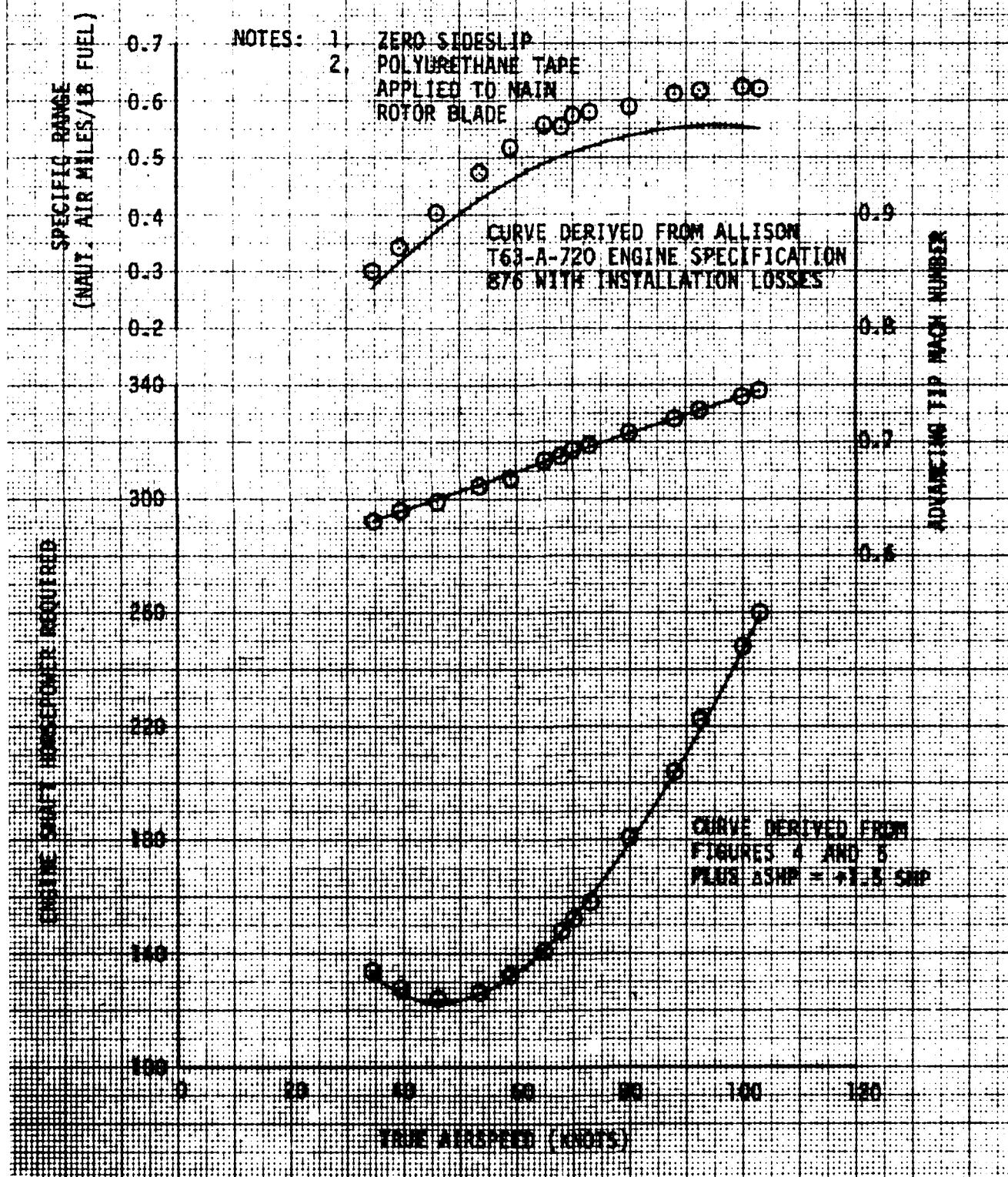


FIGURE 11  
LEVEL FLIGHT PERFORMANCE  
JOM-5BC USA S/N 20-15349

Avg GROSS WEIGHT (LB)	Avg C6 LOCATION LONG (FS)	Avg LAT (84)	Avg DENSITY (LB/FT <sup>3</sup> )	Avg ALTITUDE (FT)	Avg TAT (DEG C)	Avg REFERRED ROTOR SPEED (RPM)	Avg C T
3070	109.3 (MID)	0.1 NID	6200	16.0	353.0	0.003743	

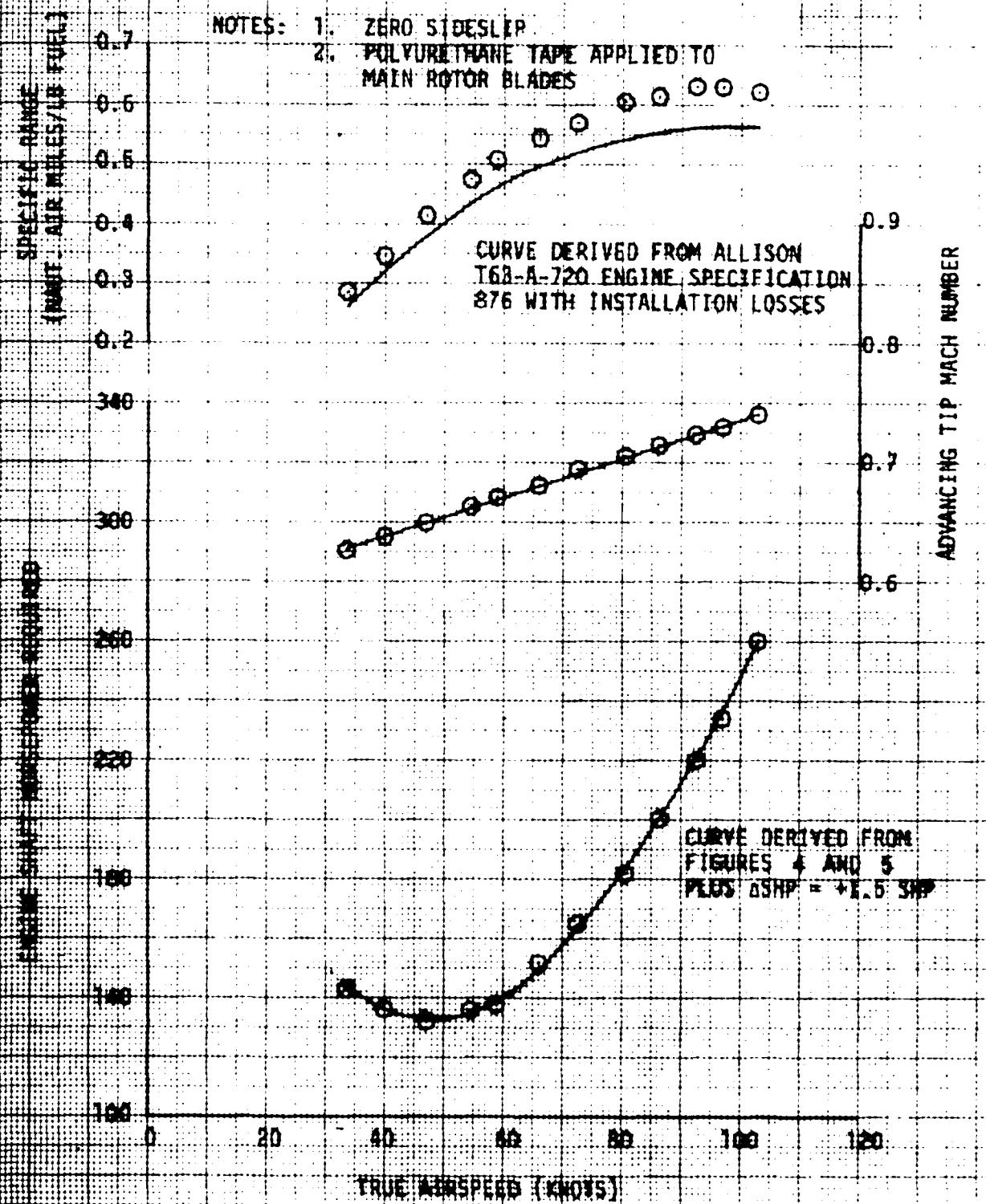


FIGURE 12  
LEVEL FLIGHT PERFORMANCE  
JOH-38C USA S/N 70-15349

Avg Gross Weight (lb)	Avg CG Location (FS)	Avg Density (lb/ft <sup>3</sup> )	Avg Altitude (ft)	Avg Ref. Rotor Speed (RPM)	Avg G <sub>T</sub>	
3100	109.5 (MID)	0.1 MED	8590	7.5	353.8	0.004251

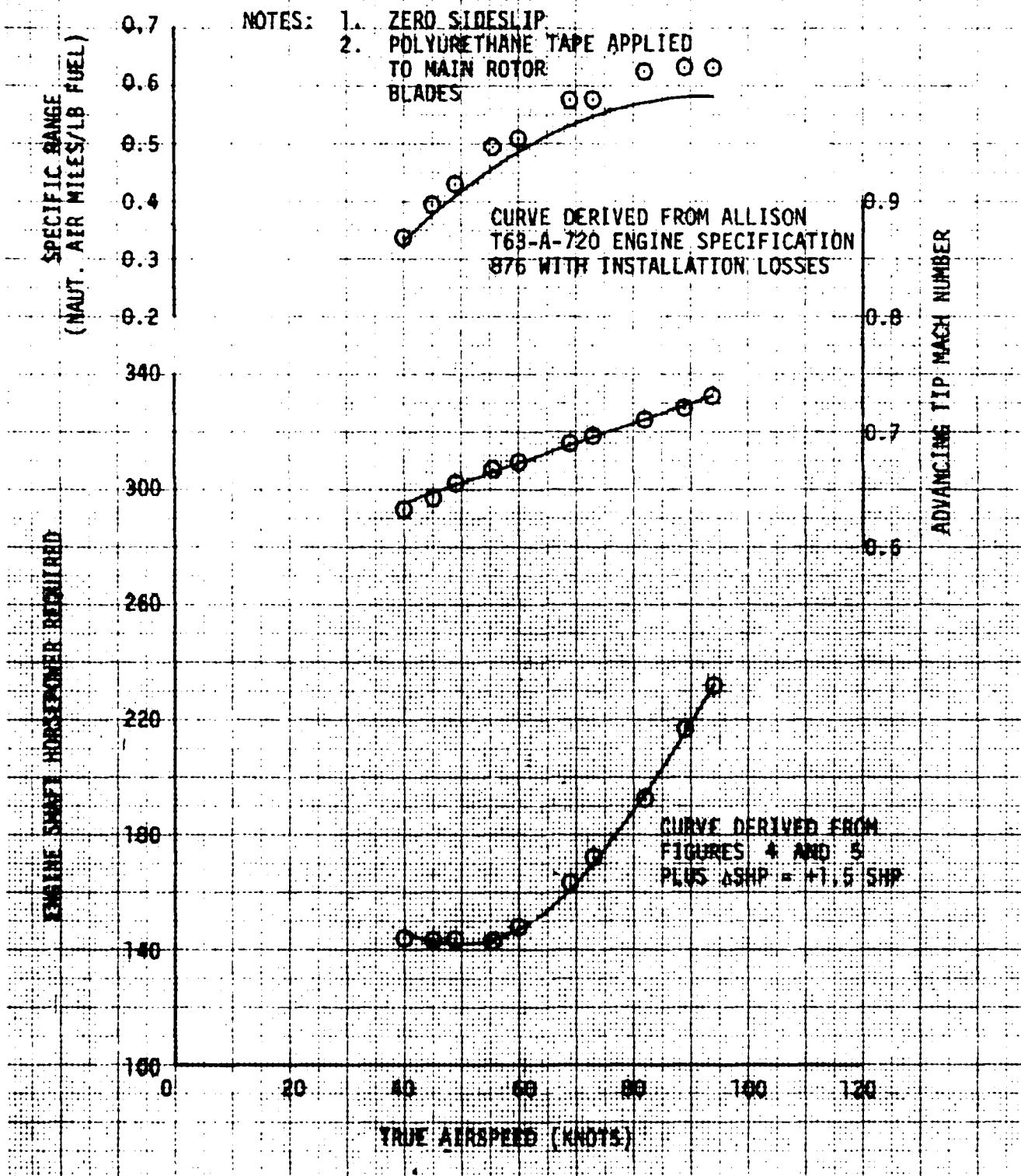


FIGURE 13  
LEVEL FLIGHT PERFORMANCE  
JOH-58C USA S/N 70-15349

AVG GROSS WEIGHT (LB)	AVG CG LOCATION EONG (FS)	AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG C)	AVG REFERRED ROTOR SPEED (RPM)	AVG C <sub>T</sub>	
3130	109.5 (MID)	0.1 MID	11,170	6.5	353.5	0.004675

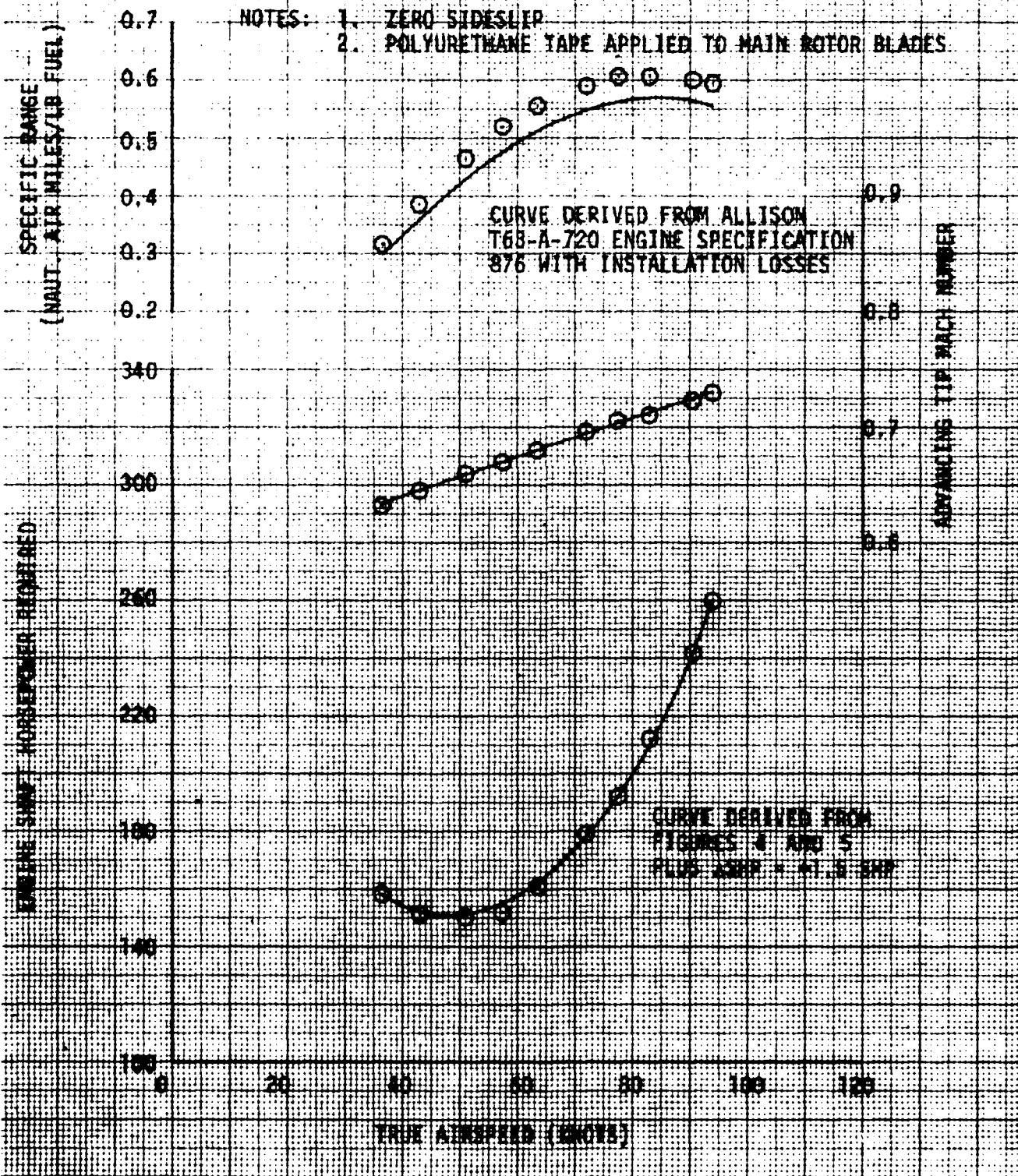


FIGURE 14  
LEVEL FLIGHT PERFORMANCE  
JOH-SOC USA S/N 70-15349

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG DENSITY ALT (FT)	AVG ROTOR SPEED (RPM)	AVG CT		
2900	110.7 (AFT)	0.1 MID	4310	14.0	353.9	0.003408

NOTES: 1. ZERO SIDESLIP  
2. STAINLESS STEEL TAPE APPLIED TO MAIN ROTOR BLADES

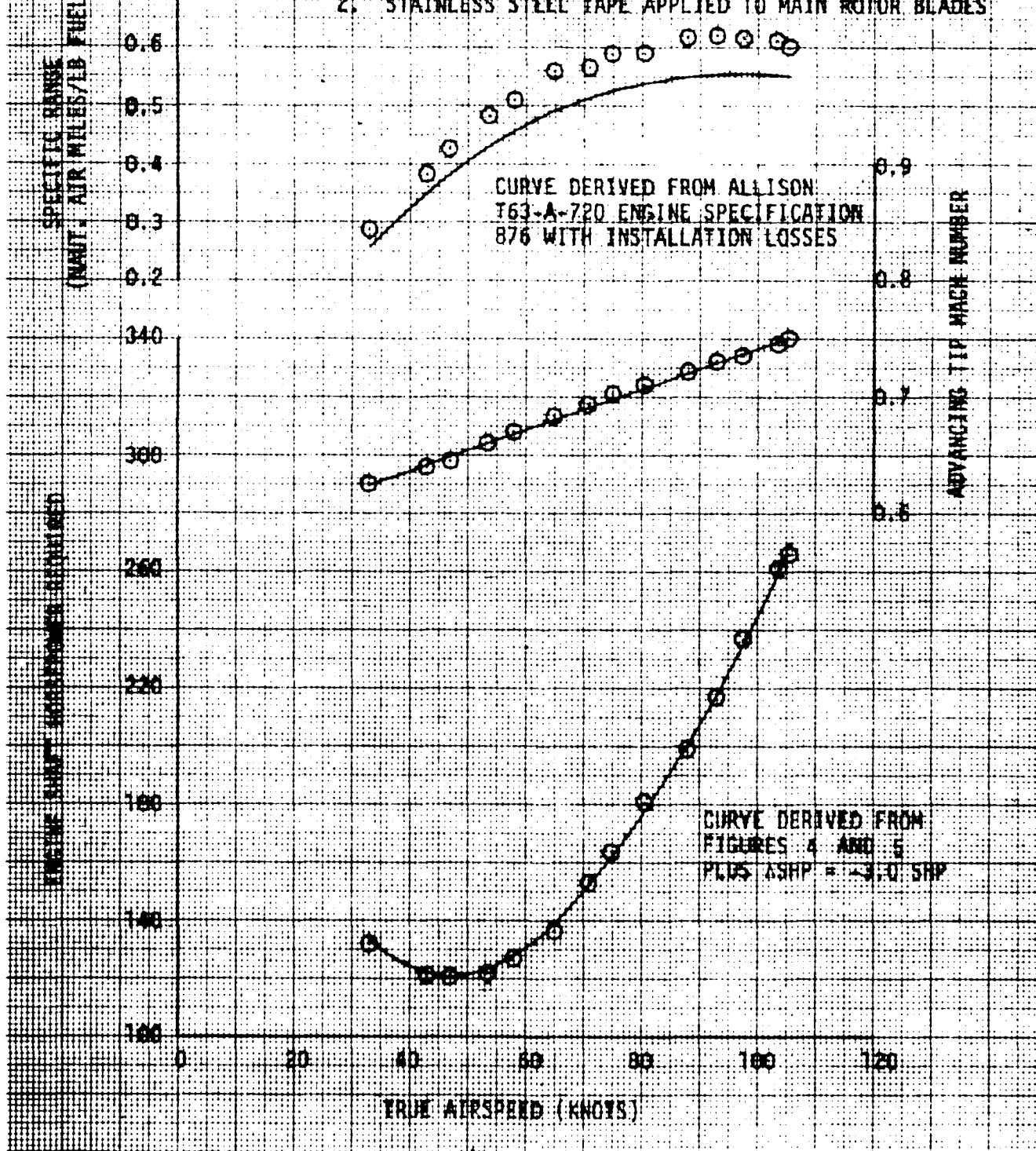


FIGURE 15  
LEVEL FLIGHT PERFORMANCE  
JOH-58C USA S/N 7D-15349

Avg Gross Weight (lb)	Avg CG Location Long (FS) Lat (BL)	Avg Density Altitude (ft)	Avg GAT (deg C)	Avg Referred Rotor Speed (RPM)	Avg ET
3000	109.3(MID)	0.1 MID	6220	15.0	353.7

3000 109.3(MID) 0.1 MID 6220 15.0 353.7 0.003726

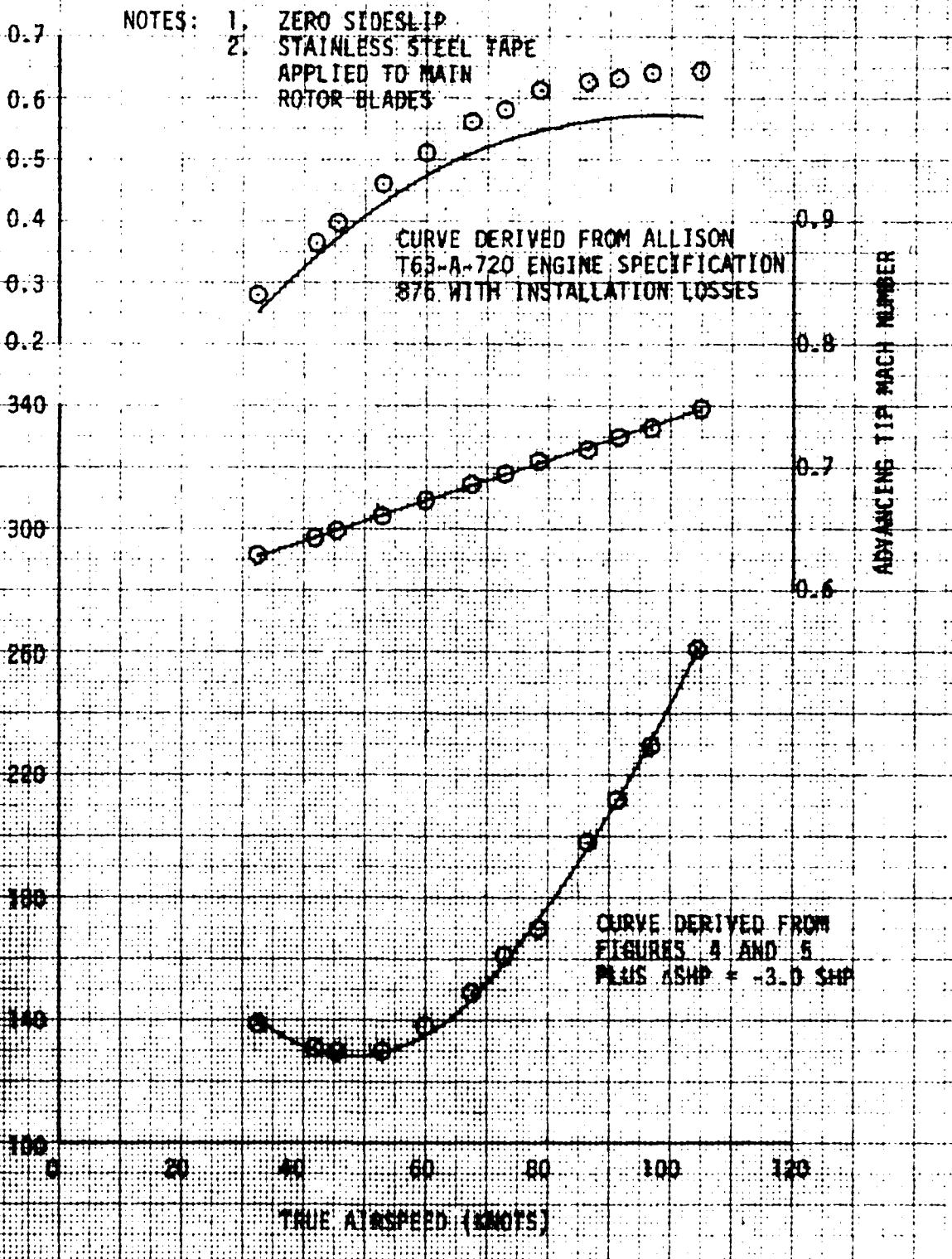


FIGURE 16  
LEVEL FLIGHT PERFORMANCE  
JOH-58C USA S/N 70-15349

Avg Gross Weight (LB)	Avg CG Location Long (FS) Lat (BL)	Avg Density Altitude (FT)	Avg OAT (Deg C)	Avg Referred Rotor Speed (RPM)	Avg $C_T$
3130	109.6(MID) 0.1 MID	8660	11.5	353.9	0.004238

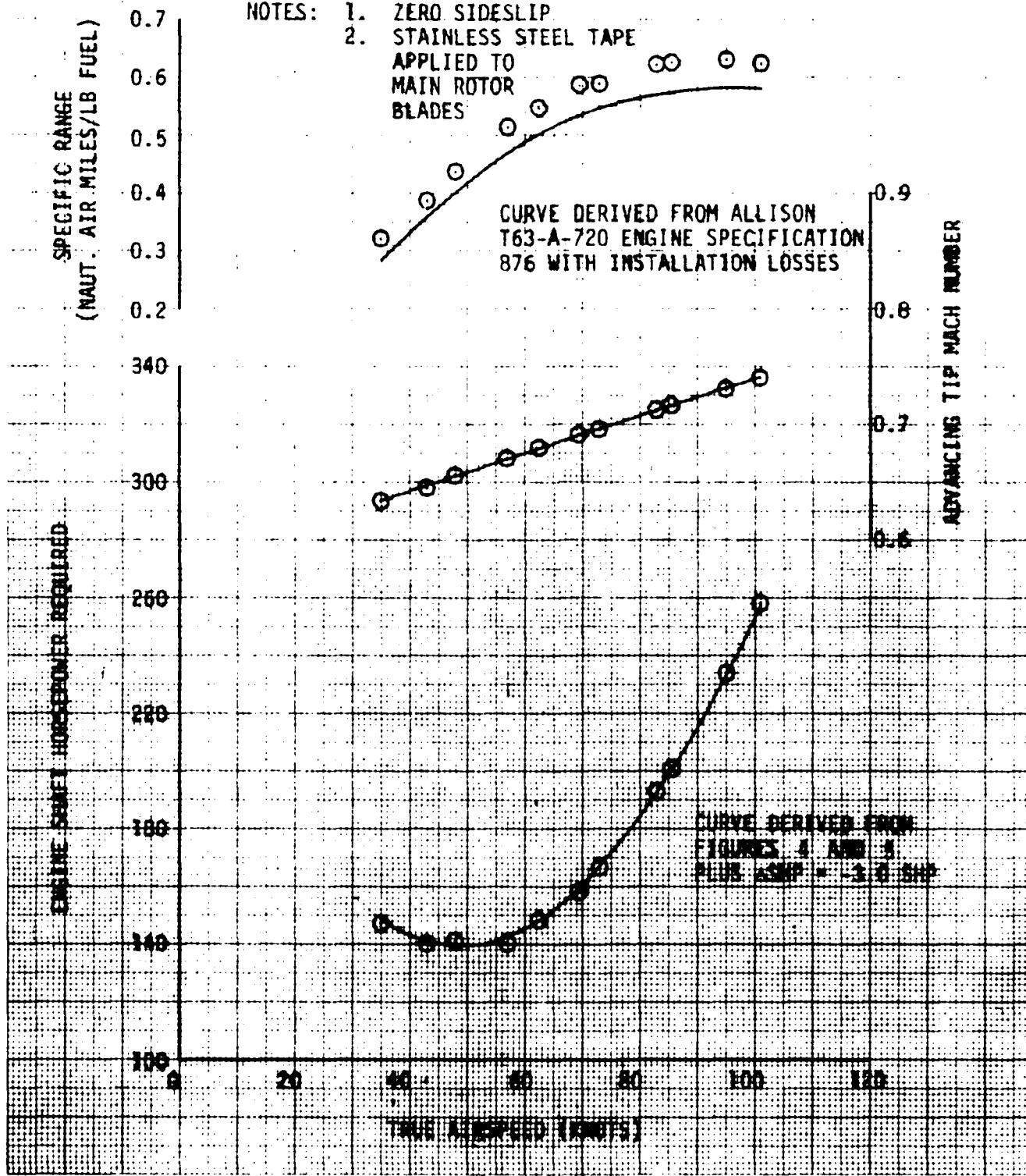
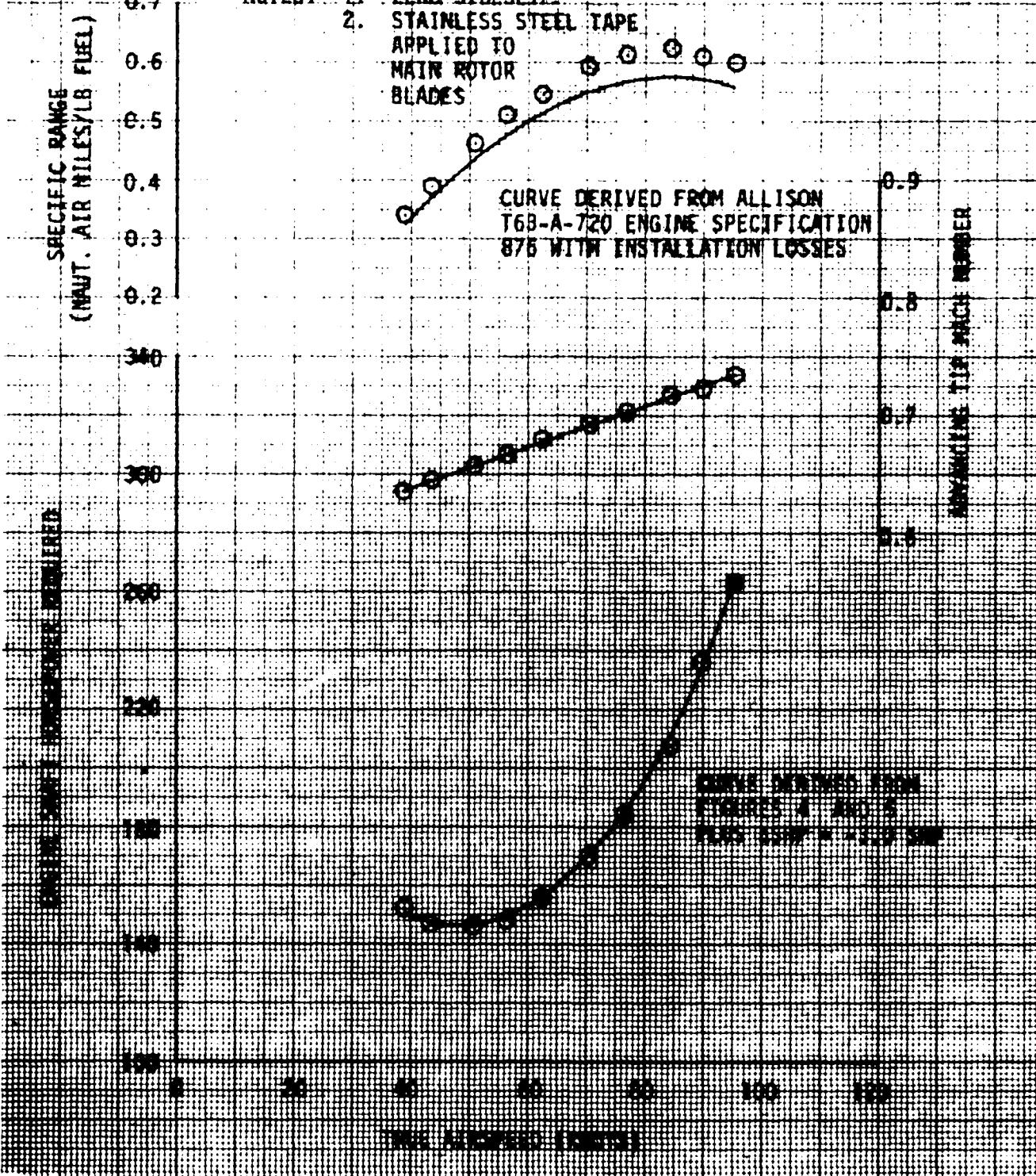


FIGURE 17  
LEVEL FLIGHT PERFORMANCE  
JOH-5BC USA S/N 70-15349

Avg Gross Weight (lb)	Avg CG Location Long (ft)	Avg CG Location Lat (ft)	Avg Density Altitude (ft)	Avg DAT (deg C)	Avg Ref. Rotor Speed (RPM)	Avg C <sub>T</sub>
3130	109.6 (MID)	0.3 MID	11,170	7.0	353.3	0.034676

NOTES: 1. ZERO SIDESLIP  
2. STAINLESS STEEL TAPE  
APPLIED TO  
MAIN ROTOR  
BLADES

CURVE DERIVED FROM ALLISON  
T68-A-720 ENGINE SPECIFICATION  
875 WITH INSTALLATION LOSSES



## **DISTRIBUTION**

HQDA (DALO-AV, DALO-FDQ, DAMO-HRS, DAMA-PPM-T, DAMA-RA, DAMA-WSA)	6
US Army Materiel Command (AMCDE-SA, AMCDE-P, AMCQA-SA, AMCQA-ST)	4
US Army Training and Doctrine Command (ATCD-T, ATCD-B)	2
US Army Aviation Systems Command (AMSAV-8, AMSAV-ED, AMSAV-Q, AMSAV-MC, AMSAV-ME, AMSAV-L, AMSAV-N, AMSAV-GTD)	15
US Army Test and Evaluation Command (AMSTE-TE-V, AMSTE-TE-O)	2
US Army Logistics Evaluation Agency (DALO-LEI)	1
US Army Materiel Systems Analysis Agency (AMXSY-RV, AMXSY-MP)	8
US Army Operational Test and Evaluation Agency (CSTE-AVSD-E)	2
US Army Armor School (ATSB-CD-TE)	1
US Army Aviation Center (ATZQ-D-T, ATZQ-CDC-C, ATZQ-TSM-A, ATZQ-TSM-S, ATZQ-TSM-LH)	5
US Army Combined Arms Center (ATZL-TIE)	1
US Army Safety Center (PESC-SPA, PESC-SE)	2
US Army Cost and Economic Analysis Center (CACC-AM)	1
US Army Aviation Research and Technology Activity (AVSCOM)	3
NASA/Ames Research Center (SAVRT-R, SAVRT-M (Library))	
US Army Aviation Research and Technology Activity (AVSCOM)	2
Aviation Applied Technology Directorate (SAVRT-TY-DRD)	
SAVRT-TY-TSC (Tech Library)	

US Army Aviation Research and Technology Activity (AVSCOM)	1
Aeroflightdynamics Directorate (SAVRT-AF-D)	
US Army Aviation Research and Technology Activity (AVSCOM)	1
Propulsion Directorate (SAVRT-PN-D)	
Defense Technical Information Center (FDAC)	2
US Military Academy, Department of Mechanics	1
(Aero Group Director)	
ASD/AFXT, ASD/ENF	2
US Army Aviation Development Test Activity (STEBG-CT)	2
Assistant Technical Director for Projects, Code: CT-24	
(Mr. Joseph Dunn)	2
6520 Test Group (ENML)	1
Commander, Naval Air Systems Command (AIR 5115B, AIR 5301)	3
Defense Intelligence Agency (DIA-DT-2D)	1
US Army Aviation Systems Command (AMSAV-EIO)	4

E

V

O

5 -

8 7

DTIC